Best Management Practices Handbook:

Hillslope Restoration in British Columbia

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Ministry of Forests
Watershed Restoration Program
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This handbook is a compilation of techniques that have been used successfully for hillslope restoration in British Columbia. Much of the information has been gained through the first-hand experience of the various authors authors and was originally published in Watershed Restoration Technical Circular No. 3: July 1994.

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Preface

This document is intended to supplement and up-date Watershed Restoration Technical Circular No. 3 - Resource Road Rehabilitation Handbook: Planning and Implementation Guidelines (Interim Methods) by G.D. Moore, 1994. It is designed as a reference handbook to assist technical staff in developing and implementing the four main stages of hillslope restoration: Planning and Inventory, Field Assessments and Prescriptions, Implementation of Works, and Effectiveness Evaluation. Although the primary focus of the handbook is on hillslope restoration, information provided may be relevant to various aspects of existing and proposed forest development.

This handbook represents a compilation of best management practices for hillslope restoration derived from Forest Renewal BC's Watershed Restoration Program and concurrent operational practices. Emphasis is on a risk-based approach to hillslope restoration that achieves effective and cost-efficient restoration practices. The intention of this document is to provide the best available technical information on hillslope restoration, while remaining independent of any present, or future, government program or funding mechanism. As well, inclusion of any technical procedure in this document does not imply that the procedure is endorsed by, or eligible under, any government program or funding mechanism. Practitioners are responsible for ensuring that all work is carried out in compliance with all pertinent legislation and regulations.

Material contained in this handbook does not constitute a standard. Rather, the techniques discussed are proven examples of practices that have been used for hillslope restoration. Practitioners are responsible for evaluating the suitability of the techniques for a given site or area. The Ministry of Forests wishes to solicit any comments, feedback or suggestions with respect to the content of this document. These can be provided by referring to the Feedback Request that follows the Annotated Bibliography, or by directly e-mailing Brendan Holden: (Brendan.Holden@gems3.gov.bc.ca) at the Ministry of Forests.

The document is formatted to allow periodic material updating. The readers should consult with local forest, fisheries and environment agencies to ensure that they have up-to-date information, or if more detail is required than is provided in this handbook.

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1.0 Introduction

1.1 Background

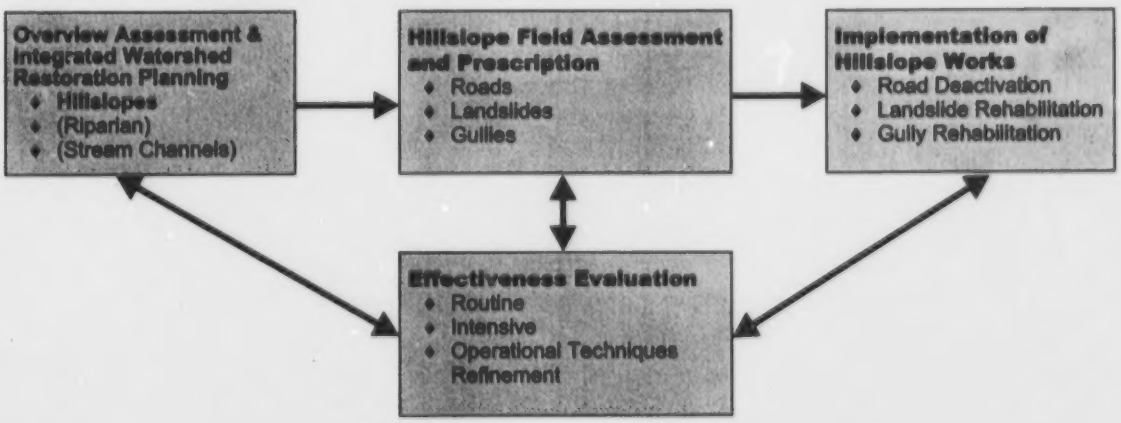
Watershed restoration began in British Columbia in the 1980's. The effort was prompted, in part, as a result of studies such as the Fish/Forestry Interaction Program that indicated logging-related landslides had caused severe degradation of fish habitat. Hillslope restoration treatments were developed to mitigate these impacts to both fish habitat and forest sites. In 1994, under the provincial Forest Renewal Plan, watershed restoration gained greater prominence with the establishment of the Watershed Restoration Program (WRP). The primary goal of watershed restoration is to accelerate the recovery of degraded environmental resources in watersheds by re-establishing pre-logging conditions, or to mitigate impacts where rehabilitation is not feasible. Restoration work within impacted watersheds is generally intended to proceed in a systematic and logical sequence beginning with overview inventories and risk assessments, followed by detailed assessments and treatment prescriptions, to implementation of prescriptions, and concluding with evaluations of treatment effectiveness. Figure 1.01 shows the main stages of hillslope restoration. A significant benefit of this work is the accumulation of experience that will contribute to better operational practices and to more sustainable forest management.

This document is based on a compilation of practical experience gained from completed watershed restoration projects. The hillslope restoration methodologies discussed have been enhanced through the province-wide practical experience of the writers and reviewers. As such, this compilation is considered to represent the current best management practices for hillslope restoration in BC.

1.2 About This Handbook

This handbook has been written and reviewed by practising professionals and technicians to provide technical guidance to forest workers engaged in any of the various aspects of hillslope restoration throughout BC, whether projects are funded by outside sources or carried out in

Fig. 1.01 Main stages of hillslope restoration.



conjunction with current forest development. The term 'hillslope restoration' in this document refers to any rehabilitation work undertaken generally upslope of the riparian zone.

Any persons wishing to familiarize themselves with hillslope restoration methodologies or upgrade their knowledge of currently accepted hillslope restoration techniques should find this document valuable as a reference.

The individual stages of hillslope restoration are addressed in Sections 2 to 9; with overview planning and inventory in Section 2; field assessments and prescriptions in Sections 3 to 7; implementation of works in Section 8; and effectiveness evaluation in Section 9. A Glossary of relevant technical terms and an Annotated Bibliography of references precede the Appendices at the back of this handbook.

1.3 Slope Stability, Erosion, and Sedimentation Risks in Hillslope Restoration

Reducing the risks of landslides, erosion, and sedimentation in sensitive aquatic environments such as fish habitat or community water supplies, are fundamental objectives of hillslope restoration. An understanding of mass wasting, erosion and stream processes is necessary to develop effective restoration prescriptions. This section provides an overview of these processes in the context of hillslope restoration and provides links to other sections of this handbook.

1.3.1 Slope Stability

Reducing the risk of landslides to downslope and downstream resources and values requires consideration of both the likelihood of an event (also termed the 'hazard') and the expected consequences. Landslide processes vary depending on the type of material and the mechanism of movement.

Hillslope stability is related to a large number of factors including bedrock geology, slope angle, surficial material(s), moisture conditions and vegetation present on the slope. The likelihood of a road-related landslide depends on this inherent hillslope stability, as well as the road locations and construction techniques used. On clearcut slopes, loss of root strength may result in a significant reduction in slope stability. In addition, the logging techniques used on steep slopes or in gully systems may reduce slope stability. For any hillslope restoration activities, the landslide hazards must be considered before field crews and equipment are deployed. The consequences of a landslide event depend, in part, on its severity, which is directly related to its size (volume or magnitude), runout distance (its length from the initiation point to the deposition area), and impact to downslope resources. For road fill failures, an evaluation of hillslope geometry and composition may be useful for prediction of severity and runout distance.

Landslides are classified depending on the type of material involved in the slide and the mechanism of landslide movement (Varnes, 1978). Different landslide types often require different considerations during assessment for road deactivation or hillslope rehabilitation. Figure 1.02 contains the landslide classification framework developed by Varnes. Although this framework has been updated recently e.g. (Cruden and Varnes, 1996), this older version is useful for operational purposes.

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly Course	Predominantly Fine
FALLS		Rock fall		Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES — ROTATIONAL	Few Units	Rock slump	Debris slump	Earth slump
		Rock block slide	Rock block slide	Rock block slide
TRANSLATIONAL	Many Units	Rock slide	Rock slide	Rock slide
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Earth flow (except creep)	Debris flow (soil creep)	Earth flow
COMPLEX		Combination of two or more principal types of movement		

Fig. 1.02 *Landslide Classification System (after Varnes, 1978).*

In this table, debris is material that contains greater than 50% coarse sand or larger fragments with organic material (woody debris). Earth contains predominantly sand, silt, and/or clay. Bedrock can be intact rock or previously weathered material.

In coastal areas of the province, common landslide types include debris slides and debris flows. Channelized debris flows (or debris torrents) and debris floods may be common in gullied terrain. In interior areas, earth slides, earth flows, earth slumps and earth block slides are more common. Rockfalls and rockslides can occur in any area of bedrock exposed or near surface. The speed and size of a landslide is often related to its mechanism of movement. Figure 1.03 summarizes many of the characteristics of forest landslide categories (after Chatwin et al, 1994).

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		BEDROCK	ENGINEERING SOILS	
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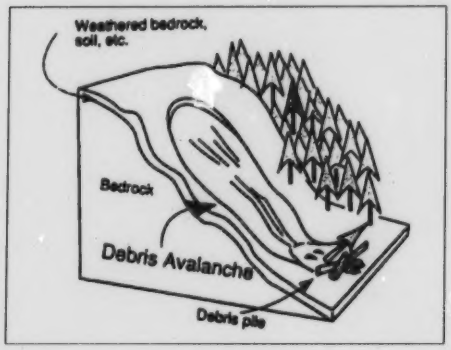
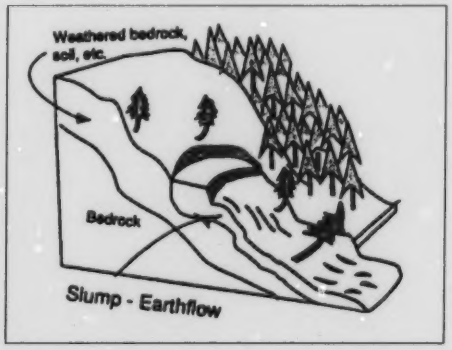
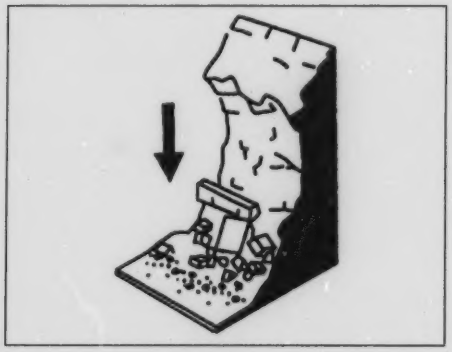
Fig. 1.03 Forest-related landslide types (after Chatwin et al, 1994).







Debris Slides (also known as debris avalanches) are rapid, shallow landslides from steep hillslopes. Movement begins when overburden slides along bedrock or along overburden layers that have higher strength and lower permeability (such as dense glacial till). If enough water is present, debris slides become debris flows. **Debris Flows** are the rapid downslope flow of debris over considerable distance. Debris flows are more common in areas with pre-existing hillslope drainage paths or linear slope depressions created by past landslide activity. Debris flows are rapid (metres/min) to extremely rapid (metres/second).

Earth Slumps and **Earth Flows** often involve the combined processes of earth movement e.g. (rotation of a block of overburden or soil over a broadly concave slip surface, or a slump) and result in the downslope movement of the block, either by a flow or through a gliding displacement of a series of blocks.

Creep activity is a common precursor to earth slumps and earthflows. Rates of movement range from extremely slow (millimetres/year) to rapid (metres/second).

Debris Falls, **Earth Falls**, and **Rock Falls** occur when the movement of the material takes place mainly through the air by free-fall, leaping, bounding, or rolling. Falls are very rapid to extremely rapid mass movements (from metres/min to metres/second). Debris falls and rock falls may present a safety hazard along older unstable road cuts or landslide headscarps.

Channelized Debris Flows (sometimes referred to as Debris Torrents) occur when debris slides or flows enter steep gully channels and canyons during high flow periods. These channelized debris flows involve the rapid movement of large volumes of water-charged soil, rock, and debris. Rates of movement are very high (metres/second) and damage can be extensive. Channelized debris flows can affect aquatic resources, and in some cases, may present a safety hazard in fan areas.

In hillslope restoration, work to prevent landslides is often carried out along the road corridor and within clearcut areas. Figure 1.04 contains information on the types of landslides that occur within these areas and the typical restoration activities that may be carried out. Note that for road corridors, the emphasis is on the prevention of landslides, while in clearcut areas the emphasis is on rehabilitation (or in some cases, stabilization to prevent further landslides and reduce erosion at the same location).

Hillslope Location		Landslide Type	Restoration Activity
Forest Roads	road cut	Slumps, Slides, Rockfalls	Road Deactivation (Sec. 3)
	road fill	Slides and Flows	Road Deactivation (Sec. 3)
Open Slopes	General	Slides and Flows	Revegetation, Bio-Stabilization (Sec. 4 and 6)
	Gully	Slides, Channelized Flows	Woody Debris Cleaning, Revegetation, Bio-Stabilization (Sec. 5 and 6)

Fig. 1.04 Landslide Types and Restoration Techniques for Hillslope Rehabilitation

1.3.2 Erosion and Sedimentation

Erosion is the wearing away of the land surface by the action of gravity, running water, wind, ice or other geological processes. Sediment generated by erosion is generally transported from a source area to a depositional area. Although erosion is a natural process, it may be accelerated by human activity. When determining the risk from erosion and sedimentation to an area, the erosion potential and the downslope or downstream connectivity to resources such as fish habitat or community water supplies must be considered.

Erosion in B.C is predominantly related to water, although in some regions erosion by wind and frost action may be significant. Erosion by water on a hillslope can occur in several different ways that may act separately or in conjunction with one another. In this discussion, soil erosion is considered to involve independent particle erosion as opposed to mass movements discussed in Section 1.3.1.

Rain splash erosion is the most basic form of water erosion and results when soil particles are dislodged and lifted into the air upon impact by raindrops. The level of erosion is dependent on the intensity and kinetic energy of the rainfall and the cohesion of the soil. Once dislodged, the soil particles may be easily washed from the slope as **sheet erosion**.

Fig. 1.05 Rilling developed on fine-grained soil, Prince George area.

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Fig. 1.04 *Landslide Types and Restoration Techniques for Hillslope Rehabilitation*

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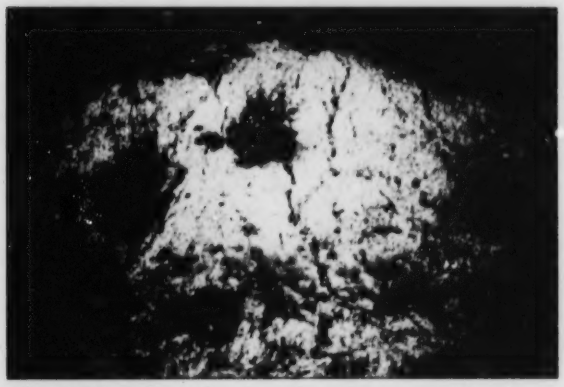

Fig. 1.05 *Rilling developed on fine-grained soil, Prince George area.*

Fig. 1.06 Headwall and transport zone of gully system well exposed after logging.

Sheet erosion acts in a generally uniform manner along the slope. **Rill erosion** may develop when runoff coalesces or merges into small channels or rills (see Figure 1.05). Erosion is concentrated at these sites due to the attendant increase in flow velocity and may result in processes such as downcutting of the channel base, undercutting of the sidewalls and 'headcutting' at the top of the rill. With continued erosion, rill erosion may develop into **gully erosion**. Gully erosion processes are similar, although on a larger scale, to rill erosion (see Figure 1.06). Large gullies can move considerable amounts of material in a very short time especially where they cross easily erodible materials. Gullies may also promote mass wasting (debris torrents) when sidewall or headwall erosion reduces slope stability. When flow in a gully is more or less continuous throughout at least part of the year, the flow is considered a stream and the erosion processes are those of **stream channel erosion**. Erosion occurs on the streambed through downcutting and along the streambanks by undercutting. Sloughing may occur within any channelized surface flow and result in streambank and channel bottom erosion.

Other types of water erosion include **solution** (erosion of soluble rock, such as limestone, when dissolved by acidic waters) and **groundwater piping** (the dislodgement and transport of soil particles by groundwater where it exits the ground to become surface water). Both processes may lead to collapse or subsidence of the ground surface.

The erosion of an area depends on several factors relating to soil, slope, vegetation, climate and erosion control practices. The Universal Soil Loss Equation (USLE) is one example of many methods that may be used to calculate erosion (soil loss). With the USLE, soil loss is the product of these factors:

$$X = R \times K \times L \times S \times C \times P$$

Where:

X = Soil Loss
R = Rainfall factor
K = Soil Erodibility index
L = Slope Length factor
S = Slope Gradient factor
C = Cropping or Vegetation factor
P = Erosion Control Practices factor

Rainfall factor (R) is based on the sum of storm energy and intensity and will generally be specific to a given region or area. Soil Erodibility index (K) provides an estimate of how erodible the local soil is and, therefore, will be site specific. In general, soils with

low cohesion (e.g. sandy soils derived from fluvial or glaciofluvial deposits) will have a high index, while soils with high cohesion (e.g. silty or clayey soils derived from basal tills) will have a lower index. Slope Length factor (L) is determined by the length of the slope at a specific slope gradient. This slope gradient defines the Slope Gradient factor (S). Together, these factors (LS) may be considered the 'Topographic' factor. Long steep slopes will be more susceptible to erosion than short gentle slopes. Topographic factor will depend on site conditions; however, it may be possible to alter Topographic factor by treatments such as resloping or terracing. Cropping or Vegetation factor reflects the cover provided by vegetation or other material (e.g. mulch, erosion control matting): a higher cover yields a lower Cropping factor. Appropriate revegetation treatment can lead to a reduced Cropping factor. Erosion Control Practices factor is dependent on the application of non-vegetative erosion control practices such as installation of check dams or silt fencing, surface roughening, etc. Any such treatments can reduce this factor.

Erosion control for hillslope restoration (i.e. reduction of Soil Loss) will, therefore, benefit from any treatments that will aid in reducing Topographic factor (LS), Cropping factor (C) and/or Erosion Control Practices factor (P).

Hydraulic connectivity refers to the "connection" of hillslope areas to larger creeks or streams beyond the toe of the hillslope. In areas of direct hydraulic connectivity, any sediment that reaches a hillslope creek is transported directly downstream at a significant gradient (i.e. greater than 5 %) to locations where it may result in adverse effects to water quality or aquatic resources. For areas with no connectivity, the hillslope stream must flow into a swamp or lake and trap sediment where water quality or aquatic resources are not a specific concern, or it must terminate before connecting with any stream reaches that have water quality or aquatic resource values. Indirect connectivity may occur where the hillslope stream flows through a lower gradient reach (typically less than 5 % gradient for a minimum length of 100 m) before connecting with any stream reach with water quality or resource values.

2.0 Planning and Inventory

2.1 Introduction

Every watershed contains its own unique set of physical attributes in terms of geomorphology, hydrology, topography and climate. Many also feature roads, landslides, gullies and stream channels that require varying degrees of restoration as a consequence of land uses (Figures 2.01 and 2.02). Successful watershed restoration depends on three fundamental procedures: identifying watershed restoration planning objectives; building an inventory of all the areas requiring treatment to meet those objectives; and developing a comprehensive plan to treat those areas.

Fig. 2.01 *Portion of the Gordon River watershed, Vancouver Island.*

Fig. 2.02 *Portion of the Bowron River watershed, north-central B.C.*

Establishing objectives is key to the restoration planning process. Objectives guide the restoration plan and are determined by outlining the most beneficial watershed restoration results that can be achieved with the funding available to accomplish the work.

Once the objectives are identified, an inventory can be created consisting of relevant data regarding the watershed features to be treated. From this inventory, an organized plan for restoration can be developed. The plan will include a sequence for undertaking treatments based on a comparison of the benefits to the watershed, and making the most beneficial activities the first priority. An effective plan will also be flexible. In some cases, lower priority sites may be treated because of logistical considerations. It may be prudent, for example, to deactivate a lower priority secondary spur trail along with a higher priority road if the road deactivation will eliminate access to that spur trail.

Benefits to a watershed are typically determined by an assessment of risk. Risk is the likelihood of an event (hazard) occurring combined with the effect (consequence) that event will have on the resources in the watershed, or, Risk = Hazard x Consequence (see the Forest Road Engineering Guidebook for a full definition of risk). Treatment feasibility may be evaluated with risk factors to determine treatment priority. Therefore, if treatment is neither practical nor cost effective, it may not be prescribed and/or implemented.

In all restoration projects, some degree of experienced and/or professional judgment is required. Figure 2.03 presents a flowchart that illustrates a typical planning process. This section will follow the structure of the flowchart

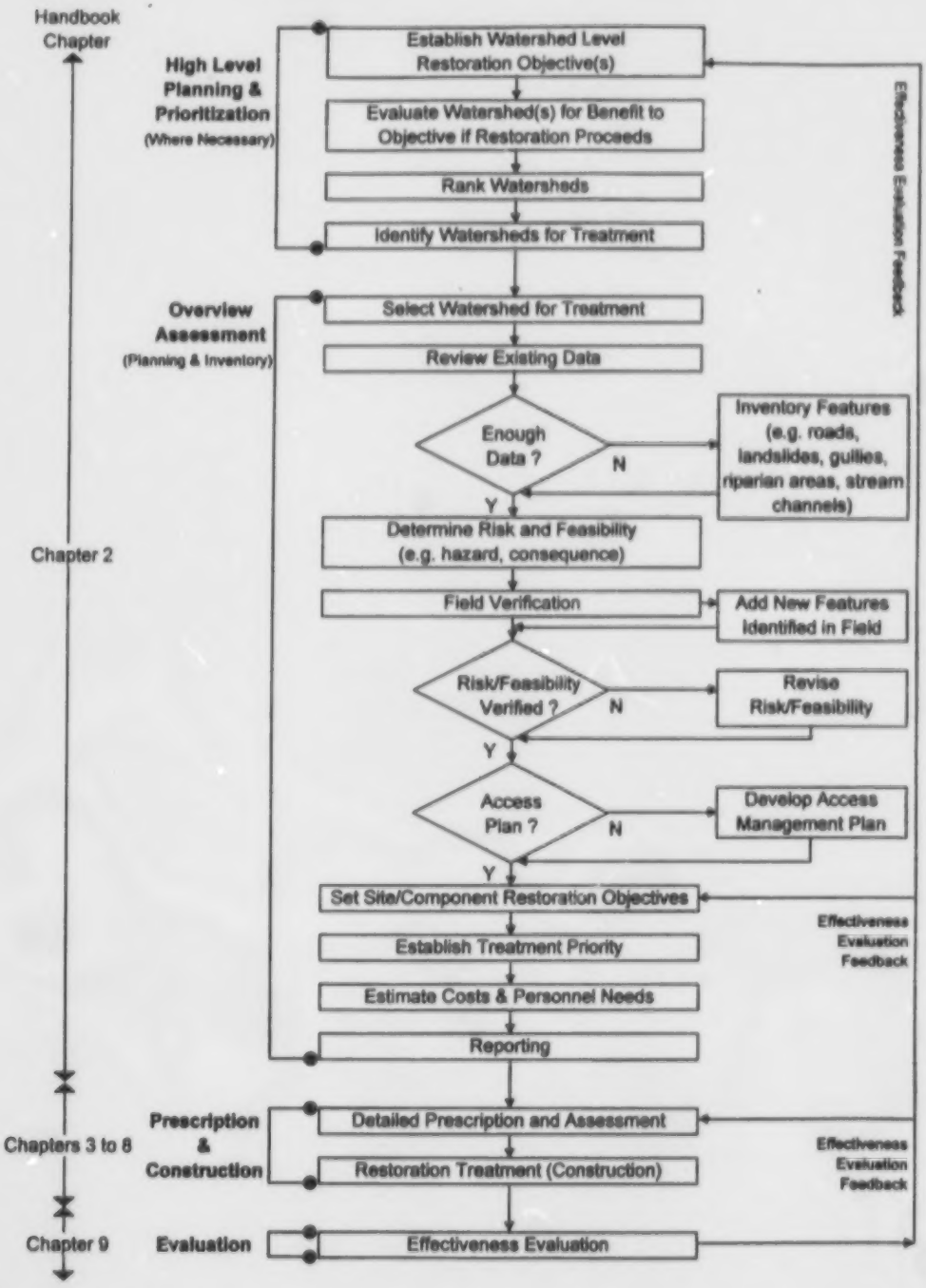

Fig. 2.03 Planning and Inventory Flowchart

2.2 Setting Watershed Priorities

Setting watershed priorities begins once the restoration program objectives are set. Common objectives include, but are not limited to:

- protecting, restoring or enhancing fish habitat;
- protecting target fish species;
- maintaining or improving water quality;
- minimizing the risk to life and property (e.g. logging camps, private property);
- minimizing the risk of disruption along transportation and utility corridors;
- re-establishing productive forest land;
- limiting access for environmental protection;
- maintaining or improving road stability following construction;
- reducing sediment delivery in the watershed;
- decreasing landslide hazard;
- evaluating previously deactivated roads against current deactivation standards and on-site residual risk to decide whether to commit more resources to previously deactivated areas.

Restoration objectives, however, can be influenced by other factors. These may include:

- objectives established under high level plans (e.g., Land and Resource Management Plan (LRMP)) or similar;
- requirements of Forest Development Plans (FDP) or similar operational plans;
- results of the overview assessment (e.g., Restoration Plans (RP) or similar);
- regulations (e.g., regulations concerning minimizing sediment delivery to streams as per the Forest Practices Code (FPC)).

Establishing watershed objectives will also assist in setting watershed priorities. The process of setting priorities will also focus available funds and effort on the critical features within a watershed project. As an example, for projects that focus on water quality and fish habitat, watershed objectives will need to be set with an explicit understanding of the connectivity between sediment source areas and critical stream reaches. If this connectivity is poorly understood, instream works may be at risk from upslope sediment delivery.

The degree and extent to which prioritization occurs will depend on the established watershed level objectives. For example, priorities set in a watershed to minimize landslide hazard will be very different from those set to enhance fish habitat. Some degree of experienced judgment may be needed.

2.3 Overview Assessments

The purpose of an overview assessment is to gauge restoration potential within a watershed. An overview assessment will also identify individual tasks, such as the revegetation of landslides or the location of sediment source areas, that need to be completed to reach the objectives set out for the restoration project.

For the purposes of Section 2, the term "overview assessment" will be considered synonymous with:

- any overviews required for operational watersheds;
- Restoration Plans required for watershed restoration;
- other comparable assessments.

An overview assessment should focus closely on identifying what development-related hazards exist, what risks they present to resources, and whether these risks can reasonably be mitigated by restoration work.

An overview assessment may include:

- identification of the impacts of past development in the context of the geomorphic processes of the watershed (e.g. areas where road construction and land-use activities have occurred);
- identification of "resources of interest" (See Section 2.4 below);
- identification of the natural and man-made sediment sources, and their potential risk to the resources of interest;
- assessment of hillslope-related hazards (primarily terrain stability), and an evaluation of the risk to environmental, social, or economic values, or to human safety;
- identification of areas and priorities for detailed assessment and possible rehabilitation work;
- identification of hazards that can reasonably be mitigated by restoration work and the recommendation of hazard sites for site specific assessment and prescription;
- identification of the need for professional input into detailed assessments and rehabilitation prescriptions
- review of existing access plans or access management strategies relative to identified hazards;
- setting priorities for completing the detailed assessments and restoration work in a logical, orderly and cost-effective manner based on environmental, administrative, and operational risks and the preparation of preliminary time schedules and cost estimates for future assessment work.

Developing an effective overview assessment will depend on the type and extent of existing information, the investigator's past experience, and the specific characteristics of the watershed. Where necessary, appropriate agency staff (e.g., the local District Manager) may approve comparable methods that achieve the goals of the overview assessment in a cost-effective manner.

2.4 Description of an Overview Assessment

An overview assessment is usually conducted at scales of 1:20,000 (Coastal BC) to 1:50,000 (Interior BC) but may vary depending on the size and specific concerns of the project watershed. The level of effort for each task will also vary depending on the specific concerns within the watershed, and the extent of existing information.

An overview assessment typically involves the following tasks:

- office-based review of existing information and local knowledge;
- inventory of watershed features to fill identified gaps in existing information;
- review of access plan;
- risk assessment of inventoried features and resources relative to identified hazards;
- field reconnaissance of affected areas and sediment sources to verify inventory;
- compilation of information gathered from previous phases, and development of recommendations for site specific assessments.

Identified resources of interest for the purpose of the overview assessment may include:

- fish habitat;
- domestic water supplies;
- human health and safety;
- property and dwellings;
- highways, railways and other transportation corridors;
- utility corridors and associated infrastructure;
- recreational areas (e.g. campsites, caves, trails).

An overview may identify types of restoration activities that should be undertaken within the project area. In some cases, there may be legal obligations to restore particular features. Any restoration plans or activities (e.g. road deactivation) developed or recommended in the overview should be consistent with the governing legal framework (e.g. FPC).

2.5 Background Information Review

The background information review is typically an office-based effort to confirm the resources of interest, identify and inventory past impacts of forest development, and make a preliminary identification of sediment-based hazards and risks within the watershed. Regulatory agencies, forest licensees, and other groups or persons with local knowledge of the watershed can provide valuable information. **Maximum use of existing information will avoid duplication of effort.**

Some typical information sources include:

- 1:20,000 scale Terrain and Resource Inventory Mapping (TRIM) topographic maps;
- 1:20,000 forest cover maps;
- Terrain Mapping, Terrain Stability Mapping (TSM) and/or soil erosion mapping;
- air photos, recent and historic;
- resource data, such as fish stream classifications, water licenses, locations of municipal or community water intakes, and private land locations (including First Nations reserves);
- previous studies completed for the watershed, such as Watershed Assessment Procedure (WAP) reports, terrain attribute studies, road inventory or condition reports, sediment source surveys, landslide investigation reports, and fish habitat assessments;
- access management maps;
- known informal recreational activities (e.g. trails, caves, campsites);

- forest development plans;
- surficial and bedrock geology maps;
- cultural feature inventories;
- current mineral tenures or mining claims;
- biogeoclimatic maps;
- regional climatic data including precipitation.

Not all of this information is readily available or relevant to all watersheds. It may be necessary to:

- update the project base maps (TRIM or forest cover) for recent roads or forest development structures;
- determine the nature and extent of impacts on these resources of interest from past forest development and natural hazards;
- identify probable sources of the impacts, including:
  - unvegetated landslides (natural and from logged gullies or slopes, and from roads);
  - natural unvegetated gullies;
  - eroding escarpments, channel banks, stream reaches and alluvial fans;
  - convex terrain with "flat over steep" profiles;
  - road elements with high chronic sediment delivery to streams;
  - road sections on steep, unstable or potentially unstable terrain;
  - large landings and large debris disposal sites;
  - old rock quarry and borrow pit areas (e.g. in fluvial terraces close to streams);
- estimate the likelihood of slope failure, continued sediment delivery, potential stream diversion (in the case of unstable stream reaches or alluvial fans) and the likelihood of impacts to resources of interest (e.g. via connectivity to streams and gullies, etc).

When identifying risk sites, consider including those sites in adjacent terrain where alteration of the natural terrain by past development could trigger potential hazards associated with features such as redirected or 'pirated' drainage, for example. Other features to be considered when identifying risk sites may include skid trails, temporary roads, yarding tracks and backspar trails where relevant.

If an inventory of watershed features is warranted during the preliminary assessment, ensure sufficient data is collected to determine an assessment of risk. An overview assessment inventory would include hillslope features (e.g., roads, landslides and gullies) and stream features (e.g., riparian and channel areas). Common attributes to inventory are discussed in Section 2.6.

2.6 *Inventory Assessment*

An inventory assessment may be necessary as part of an overview assessment, particularly if no inventory data exists. The level of data collected during the inventory is generally dictated by the overview objectives and by the information requirements of the restoration planning process.

An inventory may contain such components as roads (including road networks, landings and skid trails), landslides, gullies, riparian areas and stream channels. The scope of the inventory will vary depending on the amount of information available for the watershed. The quality of the inventory will depend on available resources and the attention given to detail. For example, inventories can be conducted by a review of historical air photos. This will provide some detail at minimal cost. Inventory quality can be improved by the use of reconnaissance overflights especially by low level, slow speed helicopter. The most detail, but at highest cost, will be obtained by foot traverses. Some degree of experienced judgment may be needed to determine what the inventory will entail.

In general, inventoried features should be numbered using a standard convention. Use of existing names is preferred. Where no such convention exists, a suitable naming convention should be developed. An example naming convention, with roads named in sequence of occurrence from the "0" kilometer marker, is provided below in Figure 2.04.

Mainline Road	Branch Road	Spur Roads	Smaller Secondary Spurs		
Mainline 100	Branch 105	Spur 105A	105A1 110A2		
		Spur 105B			
		Spur 105C	105C1	105C1A	
	Branch 110	Spur 110A	110A1	110A1A 110A1B	
	Branch 120	Spur 120A Spur 120B			
Mainline 200	Branch 210	Spur 210A	220A1	220A1A	220A1A1 220A1A2
	Branch 211	Spur 211A Spur 211B Spur 211C			
	Branch 220				
Etc.					

***Fig. 2.04** Example Naming Convention for Roads*

Consider mapping each inventoried feature on a suitable topographic base. Inventoried data may also be incorporated into a Geographic Information System (GIS) platform, if desired. If a GIS platform is being used, time and effort efficiencies may be gained if inventoried data is plotted directly on maps generated by the GIS platform that will be used to store the data. It should be compatible with industry and/or agency platforms.

If the investigator is unfamiliar with the watershed, or if available data is outdated, a brief helicopter reconnaissance of the watershed may be beneficial prior to starting the inventory. Such a reconnaissance may help identify key areas to be addressed and help focus planning activities.

The level of effort established for the inventory will determine the degree to which inventory attributes may be obtained in detail. Examples of inventory attributes are presented in Appendix I. Sufficient information must be provided so appropriate strategies for treatment can be developed. The exact nature of the strategies will depend on the objectives established for the watershed. A qualified professional may be needed to inventory features and determine appropriate treatment strategies so watershed objectives are met.

An inventory may contain such components as roads (including road networks, landings and skid trails), landslides, gullies, riparian areas and stream channels. The scope of the inventory will vary depending on the amount of information available for the watershed. The quality of the inventory will depend on available resources and the attention given to detail. For example, inventories can be conducted by a review of historical air photos. This will provide some detail at minimal cost. Inventory quality can be improved by the use of reconnaissance overflights especially by low level, slow speed helicopter. The most detail, but at highest cost, will be obtained by foot traverses. Some degree of experienced judgment may be needed to determine what the inventory will entail.

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Mainline 100	Branch 105	Spur 105A	105A1 110A2		
		Spur 105B			
		Spur 105C	105C1	105C1A	
	Branch 110	Spur 110A	110A1	110A1A 110A1B	
	Branch 120	Spur 120A Spur 120B			
Mainline 200	Branch 210	Spur 210A	220A1	220A1A	220A1A1 220A1A2
	Branch 211	Spur 211A Spur 211B Spur 211C			
	Branch 220				
Etc.					

Fig. 2.04 *Example Naming Convention for Roads*

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Watersheds covered by existing plans (e.g. FDP, LRMP) may have established management practices for identified features. Inventory requirements and treatment strategies may depend on any restoration objectives previously established under the existing plan.

2.6.1 Roads

For an overview assessment, each road may be subdivided into sections of similar landslide or surface soil erosion hazard based on a series of recognizable attributes. Possible attributes include:

- hillslope gradient;
- topography;
- terrain;
- geomorphic process;
- risk to resources of interest;
- existing stability conditions;
- assumed construction techniques and age of road.

Possible treatment strategies to consider when conducting a road inventory and estimating restoration priority might include:

- pullback of unstable road fill;
- re-establishment of natural drainage patterns;
- removal of existing culverts;
- construction of water management structures (e.g. waterbars or cross-ditches);
- seeding and planting of exposed ground;
- erosion control and sediment prevention techniques.

Factors to consider when undertaking an overview inventory of roads include:

- high risk roads may be overgrown and require ground assessment to determine existing conditions;
- the behaviour of adjacent, similarly constructed roads on similar terrain may be a good indicator of hazard;
- the risk rating is based on a qualitative assessment of the interaction of hazard and potential downslope consequences;
- if previously deactivated roads are present in the watershed, residual risk on these roads should be considered;
- if water management is the primary issue, evaluation of the areas downslope of water discharge locations may be important with respect to stability as well as erosion;
- a high risk road may be a road that has a high potential to generate or transport sediment to streams even if it has few stability problems.

Some of the inventoried road attributes may be checked during field verification or through review of the background information. See Section 3 for a discussion of treatment methods for road deactivation.

2.6.2 Landslides

The density of regenerating forest canopies may obscure landslide features if office-based inventories are conducted without some field verification. Landslides may be assessed using the Landslide Rehabilitation Assessment Procedure (LRAP) or other suitable method. Planimetric representation of landslide features may be done by:

- hand transfer (least cost, lowest precision);
- Global Positioning System (GPS) references;
- monorestitution;
- stereo plotting (highest cost, highest precision).

Treatment strategies to consider when conducting the landslide inventory and estimating restoration priority could include:

- seeding (dryseeding or hydroseeding on the ground or aerially);
- planting (shrubs, hardwood or conifer);
- fertilizing;
- stabilization of headwall areas;
- stabilization of sediment stored in deposition zone.

Because some landslide scars revegetate fairly rapidly or are obscured by the surrounding canopy, not every landslide, especially smaller events in standing timber, may be identified solely from office-based work. Also, it may not be possible to tell if a landslide scar represents more than one event (i.e., there has been more than one landslide at that location). Some degree of field verification may be needed to identify recent landslide events or determine if landslide scars represent more than one event, especially if the feature has a high risk. Revegetation on landslide scars may indicate that stability of the local surface material has increased since the landslide occurred.

Any landslide runout zones that are determined from air photos and/or overview flights and plotted on the project map base will represent the possible downslope distance traveled by landslide debris. In some cases, landslides (primarily debris flows) may travel short distances under the forest canopy without actually pushing the trees over. In these cases the true extent of the runout zone may be difficult to estimate on the air photos. A more accurate determination of runout length will require ground assessment but will have limited relevance for revegetation assessments. Field verification of runout zones may be costly and some degree of experienced judgment may be necessary to determine if the extent of runout zones needs to be confirmed.

Some of the inventoried landslide attributes may be checked during the field verification of the inventory or through review of the background information. See Section 4 for a discussion of treatment methods for landslide rehabilitation.

2.6.3 Gullies

The density of regenerating forest canopies may also obscure gully features. Since not every gully can be inventoried from air photos, it may be best to initially concentrate on those gullies that represent a significant risk to the watershed. Gullies may be subdivided

into relatively homogeneous "reaches" using the guidelines of the Gully Assessment Procedure (GAP) or other suitable methods.

Not all gullies will need to be inventoried and the selection of which ones to inventory will vary greatly from watershed to watershed and from the interior to the coast of British Columbia. Experienced judgment may be needed to establish what features to include in a gully inventory. Factors to consider when selecting inventory features include:

- importance of gullies within the watershed as transport corridors for sediment;
- existing development (e.g. harvesting) adjacent to or across gully reaches;
- noticeable gully impacts to downslope resources;
- age and type of disturbance (e.g. date harvested and methods used) in and around the gully;
- observable density of woody debris in gully, if any;
- stability of woody debris in gully, if any;
- stability of gully sidewalls and headwalls (may be inventoried under landslide inventory if landslide has already occurred);
- coupling between gullies and avalanche chutes (important in the Interior);
- distance traveled by avalanche snow and debris upon reaching gullies, if any (important in the Interior);
- number of road crossings, if any;
- presence of deep road fills at crossings, if any;
- applicable definition for a gully.

Treatment strategies to consider when conducting the gully inventory and establishing treatment priority could include:

- cleaning of woody debris (a less common practice now);
- stabilization or removal of sediment wedges;
- stabilization of gully sidewalls and headwalls.

Some of the inventoried gully attributes may be checked during field verification of the inventory. See Section 5 for a discussion of treatment methods for gully rehabilitation.

2.6.4 Riparian Inventory

For watersheds where improvements to fish habitat and water quality are the defined objectives, riparian treatments that help to stabilize sediments delivered to the channel margins, stabilize channel margins and/or minimize the risk of sediment delivery to the streams from upslope areas are beneficial. Additionally, riparian treatments may be appropriate where there is a high potential for such work to improve overall channel stability.

The inventory should identify riparian areas in the watershed and develop riparian management strategies where no strategies have been developed. Treatment strategies to consider when conducting the riparian inventory and estimating restoration priority might include:

- planting of coniferous and/or broadleaf species to re-establish forest cover;
- silviculture treatments to trees or other competing species to allow space for conifers to emerge;

When determining the appropriate treatment strategies the following information should be considered:

- The historical species (pre-disturbance) and its abundance
- Proposed restoration species
- Provision of shade for stream channels
- Provision of future LWD for stream channels
- Treatment cost / benefit compared to hillslope / road work

2.6.5 Channel Inventory

Where channels appear to have been affected by upslope activities, or where improvements to water quality and fish habitat are the defined objectives, an inventory of stream channel characteristics prior to embarking on restoration prescriptions and treatments may be beneficial. Channel inventory provides a baseline of data that can be used to monitor the effectiveness of the upslope works.

The impact of landslides and sediment delivery from roads on stream channels depends on the connectivity between the stream channel and the sediment sources. An inventory of the channel characteristics may identify whether the channels have been disturbed or not and provide a basis to determine the extent of future potential disturbances. The inventory may show that stream channels are amenable to treatment because the supply of material from the hillslopes is limited.

The inventory should identify affected stream channels and develop in-stream management strategies if no strategies exist. Treatment strategies to consider when conducting the stream channel inventory and estimating restoration priority could include:

- willow staking of in-stream sediment;
- placement of bank stabilization along channel margins;
- placement of woody debris or other habitat enhancing structures;
- establishment of side or back channel habitat.

The density of established forest canopies and their proximity to stream channels may obscure channel features if office-based inventories are conducted without some field verification. Since not every stream can be inventoried from air photos, it is best to concentrate on those streams with potential fisheries habitat that are classified/stratified using the S1-S4, Forest Practices Code designations. Additionally, S5 and S6 streams with direct connectivity to S1-S4 streams may also be considered. These streams can be subdivided into relatively homogeneous "reaches" using the guidelines of the Channel Assessment Procedure (CAP) or other suitable procedure.

High embankment fills immediately adjacent to stream crossings can be a cause for specific concern. Where these fills occur on shallowly sloped terrain they may not be

identified in the hillslope inventory. Identification of these areas of potential sediment delivery to creeks can be critical to the successful restoration of water quality and fish habitat.

Fish habitat restoration and channel stabilization success will depend largely on reducing the volume and frequency of sediment supplied to the stream channels. Where sediment supply is already limited, channel restoration may be considered. Suggested strategies for channel and riparian rehabilitation may be developed during the overview but these strategies may change as watershed restoration progresses.

2.7 Risk Assessment

The risk assessment develops risk ratings for the potential impacts on resources of interest identified in the preliminary assessment. Example risk assessment procedure outlined in the Forest Road Engineering Guidebook or any other comparable method that clearly describes the hazard (or likelihood of occurrence) of events and the risk to resources of interest may be used. For the purpose of the overview assessment, estimates of hazard and risk are usually qualitative.

For each source of impacts identified in the preliminary assessment, the following may be undertaken:

- estimate the hazard (probability or likelihood) of failure, continued sediment production, or in the case of unstable stream reaches or alluvial fans, potential stream diversion;
- estimate the likelihood of impact to the resources of interest (directly or via connectivity to streams and gullies, etc.);
- estimate the potential consequence on the resources of interest;
- if the hazard is moderate or high, indicate whether the hazard is short term or long term. A short-term hazard is one that is considered imminent. Long term hazard is typically associated with latent instability that may occur;
- for each source, identify whether the hazard or consequence could reasonably be mitigated by restoration work;
- determine the residual risk of previously treated sites and evaluate the cost of mitigating this risk versus the benefit to the project area;
- identify whether the site may be easily accessed or if reactivation/rebuilding of a road is necessary to reach a site and develop an estimate of costs;
- identify problem sites that are not eligible for funding under current regulations;
- identify the state of vegetation cover on risk rated sites. Vegetation may affect access on the site and may have implications for site stability and erosion.

The determination of hazard may be made from a combination of the following factors:

- air photo interpretation;
- terrain contours (e.g. slope ranges);
- environmentally sensitive area mapping (e.g. Es1 and Es2 polygons);
- reconnaissance Terrain Stability Mapping (TSM, e.g. P and U polygons);
- detailed TSM (e.g. Class IV and V polygons);

- experienced judgment (by a qualified registered professional where appropriate).

The determination of consequence may be derived from the available consequence (impacts) information collected during the preliminary assessment. Where appropriate, experienced judgment may also be used to determine consequences in consultation with stakeholders.

Treatment feasibility may also be considered part of the risk assessment depending on the type and scope of the overview required. Any restoration treatment can reach a desired objective given sufficient funding. However, limited funding is typical and treatment options may be constrained to the point that feasible options will not produce a benefit. Considerations when evaluating treatment feasibility may include:

- site accessibility;
- technical aspects of proposed treatments (e.g. will reasonable type of treatment provide benefit);
- cost/benefit with limited available budget (e.g. will allotted budget provide benefit).

Examples of hazard and consequence criteria and risk determination matrices for use in office-based overview assesements and for identifying project priorities are presented in Appendix II. The criteria and matrices presented are illustrative examples only and should not be considered as a procedural standard. Criteria will likely be specific for each watershed and should be developed using professional and/or technical experience and judgment and in consultation with stakeholders.

2.8 *Field Verification*

The level of effort involved in field verification must be consistent with the established watershed objectives. For an overview assessment, the objective is to assign priority to risk sites and identify what sites should be investigated in detail for site-specific remedial work. It is not necessary to field check every potential risk site at this stage. If certain roads are clearly unstable from airphotos and known information, it is not necessary to visit each one to determine that these roads should be targeted for deactivation assessments.

Air photo interpretation, review of topographic maps and helicopter overviews may be more cost-effective techniques to assess the potential for impacts to a particular site than on-the-ground field investigation. It is expected that a field reconnaissance will be undertaken to confirm or adjust the preliminary information on impacts and hazard sites in the inventory. Project personnel must exercise judgment as to the best methodology and appropriate level of effort for this task.

The level of effort invested in the field reconnaissance will depend on the extent of existing information, and on the investigator's personal knowledge of the watershed (whether from previous field work or other means). It will also depend on existing access into the watershed. The watershed may have limited road access, for example, because major drainage structures have been removed, or the area is ground accessible only by barge or winter road, etc.

Although a helicopter overview flight is generally recommended, if good road access is available field reconnaissance can be carried out mainly by vehicle. If road access is limited, the field reconnaissance may be limited to a helicopter overview with stops at critical sites where it is possible to land, and traversing of questionable areas that are overgrown.

The coverage of the field reconnaissance should be sufficient for the investigator to confirm his/her understanding of terrain conditions, stability and erosion events, natural sediment sources and stream characteristics, and the nature of impacts that have occurred to the resources of interest. The actual time spent in the field will vary depending on the size and characteristics of the watershed, the specific restoration objectives of the project and access conditions.

No fieldwork should be conducted with snow on the ground, or under weather conditions that hamper visibility or represent a significant safety issue. A brief discussion of safety issues is presented in Section 8.4 of this handbook, but practitioners should be familiar with the relevant safety regulations.

If at any time, a high or very high risk to dwellings, rural or industrial development, highway, public utility or water supply is identified, the Ministry responsible for the assessment should be immediately notified in writing.

Some means of recording information in the field include:

- field forms or other tabular means of data capture;
- video record of any overview flights;
- photographic record of any foot traverses;
- GPS locations of specific features if GPS coordinates can be obtained;
- time and/or date stamps on video and photo records if available.

Field recording techniques may vary widely between projects. Field forms, if used, should be developed for each specific watershed or project. General factors for consideration may include:

- terrain attributes including, bedrock, slope morphology, soil types;
- slope geometry;
- road prism geometry (e.g. fillslope length, cutslope height);
- presence or absence of residual fill on roads or past restoration efforts;
- restoration status of road segments (e.g. level of deactivation);
- recommended restoration prescription;
- gully geometries, including gradient, gully wall angle and gully depth;
- presence of unstable fills at gully crossings;
- presence or absence of armouring at outlets of water management structures;
- number of fish stream crossings;
- condition of bridge crossings;
- condition of roads;
- proximity to lakes or streams;
- number of large culverted embankments;
- current road use;
- sediment sources;
- condition of drainage networks.

Fig. 2.04 Example field card for field verification of road conditions

Deactivation review field notes: Road:_____Page_____of_____.

Attribute	1	2	3	4	5
Station #'s					
Deactivation proposed					
Actual Deactivation					
Deactivation date					
Terrain					
Bedrock					
Slope morphology					
Soils					
Seepage present?					
Slope Range (%)					
Gully gradient					
Gully wall angle					
Gully depth (m)					
Stability conditions					
Surface erosion					
Residual fill present?					
Residual fill instability?					
Pullback complete in gullies?					
Gully gradients re-established?					
Stream gradients re-established?					
Cross-ditch water directed to steep slopes below?					
Residual fill at cross-ditch outlets could fail?					
Excessively armored cross-ditch					
Seepage sites/cross-ditch adequately armored?					
Cross-ditch/slopes>50% excav to natural gradient?					
Outsloping?					
Unnecessary deactivation?					
Will residual fill erode into streams?					
Revegetation	**1**	**2**	**3**	**4**	**5**
Seeded?					
Date?					
Germination?					
% cover					
Conifers?					
Shrubs?					

Station #s	Photo #	Comments:

Fig. 2.05 (below) Example field card for field verification of road conditions observed from helicopter.

Road/Slide/ Gully	GPS Location	Terrain	RP#	Slope gradient (%)	Cut height (m)	Stability/ erosion indicators	Rehab status	Rehab prescript	On-site staff P/T/PT
Comments/photos:									
Comments/photos:									
Comments/photos:									
Comments/photos:									
Comments/photos:									
Comments/photos:									

Notes: Stability/erosion indicators: TC=tension cracks, VD=vertical displacement, RTF=road fill failure, XE=x-ditch erosion, SRS=severe road surface erosion , Staff; P=professional, T=technical.

Area:_____ **Watershed:**_____

Date:_____ Recorded by:_____

Factors to consider when planning and undertaking ground investigations include:

- proportion of features to be field verified;
- proportion of sites to be ground checked;
- proportion of sites to be checked from the air;
- extent of High and Very High risk sites;
- requirements, where appropriate, for assessment by qualified professionals;
- purposefully conservative approach of office-based inventories.

The field verification also allows for limited updating of landslide activity, which has occurred subsequent to the date of the air photos used for the overview. Any additional landslides that have occurred since the most recent set of air photos reviewed should be considered for inclusion in the inventory.

Factors to look for during field verification include:

- tension cracks and slumps in road fills;
- eroding road surfaces and deeply scoured ditchlines connected to streams;
- high, culverted embankments with signs of instability (e.g. ravelling);
- fresh ravelling or terrain disturbance within landslides;
- seepage indicators;
- disturbed soils in gullies;
- eroding channel margins;
- connectivity of sediment sources to stream channels.

In some watersheds where previous road deactivation has occurred, field verification may be necessary to identify whether any residual risk remains along the previously deactivated road and whether this residual risk is acceptable.

2.9 Access Management Planning

Access management planning identifies current and future access needs within the watershed so that roads which may be needed for access are not deactivated without due consideration. Access requirements vary widely from watershed to watershed. Watersheds under current Forest Development Plans (FDPs) will commonly have an access plan already in place. Also, access plans may be in place if higher level planning (e.g. LRMP) exists for the watershed. If additional access management planning is required, the existing plans should be used as a base for further work as they will have commonly undergone some form of public review. Experienced judgment may be needed to establish how much and what form of access management is still required in the watershed under study. Where an access management strategy is not available, an appropriate strategy should be developed for review and consultation with the suitable agency representative (e.g. District Manager).

The goal of an appropriate access management strategy is to integrate the watershed restoration plan with the needs of the various users of the watersheds. An access strategy should be developed for each specific road within the watershed. It is recommended that some degree of distinction be made during access planning between people who have a tenured right to access

within the watershed (e.g. forestry companies, utilities, mining claims holders, grazing leaseholders) and those who desire public access (e.g. hikers, bikers, spelunkers, hunters, fishers).

Where no access plans are in place, public access issues need to be included in the overview assessment. The relevant agencies may require that the plan be put through a public consultation process. The typical product of an access management strategy conducted for a restoration plan is an Access Management Map (AMM). The exact requirements for the access management strategies and the resulting AMM will need to be assessed on a district by district basis through consultation with the relevant stakeholders.

Some of the stakeholders (users) who may need to be considered during access management planning may include:

- the public (e.g. informal or organized groups such as recreation groups);
- licensees;
- companies (e.g. ecotourism firms);
- First Nations;
- trappers;
- agency staff;
- mineral exploration claims holders.

It is possible that access conflicts may be encountered for which resolution lies beyond the scope of the watershed restoration project. If such conflicts are encountered in areas of high risk, it is recommended that these be identified as sites for discussion with the relevant stakeholders. Such discussions may commonly lie beyond the scope of the overview project.

Various access levels may be considered when planning or managing access within a watershed. Typical access levels include but are not limited to:

- 2 wheel-drive vehicles;
- 4 wheel-drive vehicles;
- All-terrain vehicles;
- Bicycles;
- Foot access.

Appendix 3 includes typical drawings of road deactivation techniques that may be used to address these access levels.

Example issues for access consideration during an overview may include:

- seasonal and informal recreational access (e.g. fishing, hunting, hiking);
- commercial recreation access (e.g. ecotourism, rafting, snowmobile and mountain bike tours, guides and outfitters);
- operational access (e.g. hauling or salvage);
- caving access (in areas with limestone or other cave-forming environments);
- mining claims access;
- traditional lands access;
- traplines access;

- access to communications facilities (e.g. radio beacons, cellular telephone towers, microwave relay sites);
- access to transportation or utilities infrastructure (e.g. railways, pipelines);
- access to remote sites (e.g. Coast Guard access to lighthouses in coastal areas);
- access for other road deactivation;
- fire suppression access (important in the Interior);
- rangeland access;
- silvicultural access;
- construction timing windows (e.g. noxious weed control, fish windows).

When conducting access management planning, proposed plans should consider existing road conditions, slope processes and downslope resources. For example, planning may include future road use considerations with recommendations for:

- permitting of roads required for regular industrial use. Such roads should be maintained where appropriate and as required by the FPC;
- where the road is required for non-industrial use, the road should be deactivated to standards appropriate for user needs, and select sections may require structural upgrades or relocation;
- where the road is not required for either industrial or non-industrial use, or the road presents a significant risk to the watershed, the road should be deactivated to standards that minimize the risk to the watershed to an acceptable level;
- where the road is overgrown and/or access to the area is extremely difficult such that disturbances and damage caused by carrying out rehabilitation works may have a net negative effect on the watershed, the road should be left alone.

The access management plan should seek to match the listed road strategies with the identified access needs while recognizing the need to minimize the risk to the watershed from the road network.

2.10 Development of Restoration Objectives

Restoration activities should coincide with the overall watershed restoration objectives. Established restoration objectives should be amenable to monitoring (e.g. effectiveness evaluation or comparable process) so that the effectiveness of the restoration activities can be assessed. Restoration objectives may be set at several levels including watershed level objectives, component level objectives and site level objectives.

Feedback from the monitoring of restoration activities will enhance planning, strategy selection, treatment design and cost-effectiveness. However, the feedback benefit will only be achieved if measurable, obtainable objectives, goals and/or targets are clearly set at the beginning. Evaluation of restoration activities should be carried out so that the effectiveness of the applied restoration treatments may be discerned.

For example, the following watershed restoration objective has been set for a project area:

- Watershed restoration objective: maintain or improve water quality at current levels.

To meet this objective, then the component level objectives could be developed as:

- hillslope component: reduce sediment supply to streams from roads and landslides to natural levels;
- channel component: stabilize sediment stored within channels and enhance channel bank stability.

These watershed objectives and component goals are used to fine tune the treatment priority of sites and suggest applicable restoration strategies. Restoration strategies that may be considered when setting site level objectives may include but are not limited to:

- pullback of oversteepened fills;
- seeding of exposed landslide scars;
- removal of culverts at stream crossings;
- stabilization of channel margins and sediment stored within the channel.

Site-level treatment targets may be set for each of these restoration objectives. Examples of corresponding treatment targets could be:

- pullback of all high and very high risk rated oversteepened fills;
- establishment of 65 % vegetation cover within three years of treatment on all seeded landslides;
- removal of all high and very high risk rated culverts;
- stabilization of 65 % of exposed gravel bar surfaces and all harvested channel margins within 3 years of treatment.

Treatment targets are set so that the restoration activities may be evaluated for effectiveness. Some of the restoration activities should be evaluated at the end of construction (e.g. if treatment target is to build a cross-ditch to manage flow, then target has been attained if cross-ditch is built and flow managed). The cumulative effect of completed site level treatments may then be evaluated against the component level goals to determine if these goals have been met. The net effect of addressing the component goals may then be evaluated against the established restoration objectives to determine if the restoration activities have met the watershed objectives.

Section 9 of this handbook expands on the concept of effectiveness evaluation for watershed restoration.

2.11 Assessment of Restoration Treatment Priority

Where the hazards can reasonably be mitigated by restoration work, it is usually beneficial to assign priority to sites based on their potential consequences to the resources of interest. Generally, the treatment priority ratings are derived directly from the inventoried risk ratings. However, treatment priority ratings may differ from inventoried risk ratings as a result of field verification data and experienced judgment. Adjustment of the priority rating relative to the risk rating depends on the circumstances in each watershed.

2.12 Cost Estimates & Personnel Requirements for Detailed Assessments

Any estimate of the cost and personnel requirements for detailed assessment and prescription work will depend on the specific characteristics of the watershed. Cost estimates for detailed assessment and prescription development should be completed as part of the overview report. Cost estimates will depend greatly on a range of factors. Typical factors to consider may include:

- type and condition of access into watershed or along road network (including accessibility by all-terrain vehicle or four-wheel drive vehicle);
- degree and type of vegetation covering road network;
- degree and type of vegetation covering landslides;
- size and accessibility of landslides;
- presence of unstable material on landslides;
- density of road network;
- distance from stream channels to road network;
- density of debris and vegetation in gullies;
- seasonal factors such as weather, seasonal access and time of year (e.g. snow cover);
- need for helicopter access and availability of helicopter drop sites or landings in remote areas;
- estimated risk rating from overview (high hazard/risk areas often require more effort);
- interpreted hazard rating from overview (high hazard areas may require crews of two people working together for safety reasons);
- proximity to other crews and radio contact with these crews;
- size of crew required.

Additional cost factors associated with detailed assessments and prescriptions may be included in the cost estimates that accompany the overview report. Typical factors to keep in mind include:

- equipment costs (e.g. any necessary specialized field gear);
- requirements, if any, for helicopter time on overview flights;
- use, where appropriate, of qualified registered professionals;
- accommodation and meal costs;
- travel costs.

Cost estimates will need to reflect the time requirements for both office work and field work.

2.13 Overview Reporting

Specific details that should be included in an overview report or similar planning document, will vary depending on the characteristics of the watershed involved. Typically an overview report might include the following:

- a brief description of the project watershed including access constraints, seasonal constraints, possible fisheries window constraints, and other information pertinent to restoration work;

- a brief description of the physiography of the watershed including area, landform history, present-day natural processes, distribution of slope types and the range in elevations within the watershed;
- a brief description of the geology of the area including identifiable major fault traces, type of bedrock, nature of surficial material (e.g. colluvial blankets) and known mineral occurrences in the watershed;
- a brief description of the climatology of the watershed, commonly derived from an established series of climate normal stations run by Environment Canada including relevant data such as annual precipitation, daily rainfall totals, occurrence of snow and the duration of the wet season (although the closest station to the project watershed or with similar elevation and aspect characteristics may be used, considerable extrapolation and experienced judgement may be required);
- hydrologic behaviour of streams (e.g. response time of streams in coastal areas, implications of hydrology for work timing and sediment management requirements);
- a summary of the field reconnaissance indicating time spent, sites visited, and factors which may have limited the extent of the field reconnaissance;
- recommendations for restoration actions or works, and site-specific assessments needed;
- a discussion of the expected effectiveness of the remedial works at reducing risks to the resources of interest;
- the risk assessment described in Section 2.7 with site priorities assigned for restoration (presentation in a summary table is preferred; the table should include the type of remedial work needed and the type of site-specific assessment to be done, i.e. road deactivation prescription needed);
- where possible or appropriate, a proposed work plan with time frames for the detailed site assessments and remedial work to be carried out in a logical, orderly and cost-effective manner;
- depending on how the project is to be delivered, preliminary cost estimates for detailed assessments and site work are likely to be required either in the report or as an appendix submitted separately.

It is useful to include a summary of land uses and resource values in the overview report if summaries of this information are not already available. Example uses and values for consideration include:

- forestry activities including date and extent of harvesting;
- mining activities including date and extent of mining and current mineral claims;
- existing and potential recreation opportunities;
- extent of target fish streams, type of fish present, escapement numbers, barriers to fish, and suitability of fish habitat;
- number and location of water licences;
- known cultural sites and First Nations traditional use of the land within the sub-basin;
- extent of private lands, public lands and rights of way (e.g. transport or pipeline corridors, hydro transmission lines, railway lines).

Where appropriate, the professional taking responsibility for the work must have expertise in assessing geomorphic and fluvial processes and slope stability, and have basic knowledge of forest harvest systems and forest road engineering. A qualified registered professional should sign all overview reports. The Forest Practices Code defines a qualified registered professional as a person who:

(a) has appropriate education and experience to carry out the activity, and

(b) is a member of, or licensed by, a regulatory body in British Columbia that has the legislated authority to regulate its members or licensees performing the activity.

3.0 Road Deactivation Assessments and Prescriptions

3.1 Introduction

Detailed field assessments and prescriptions for road deactivation may be carried out as as part of hillslope restoration for roads or road segments. Often these will be identified in an overview assessment as having potential risk to downslope resources and values. Appropriately qualified field personnel usually carry out these assessments and prescriptions and the use of qualified registered professionals may be necessary.

For project areas with many kilometres of road requiring deactivation, it may be prudent to only assess and prescribe the amount of road that can be deactivated in one field season. This staged approach will also help to ensure that field markings are 'fresh' and that the most recent information is available. There may also be logistical benefits in coordinating efforts with operational deactivation crews, road construction crews, and salvage operators.

Treatment prescriptions are influenced by factors such as:

- site level restoration objective(s);
- current level of access;
- proposed deactivation level;
- desired final access strategy;
- stability at the site as well as the slopes below the site; and
- risk assessment.

The deactivation plan is based on the deactivation prescriptions. This plan may include a revised prioritization of road segments for treatment, a schedule of work and associated cost-estimate for the work, a summary of equipment and personnel requirements and considerations for agency review and approvals.

This section is concerned with the development of road deactivation prescriptions but also provides information and recommendations for implementation of the prescriptions. It includes:

- a suggested methodology for developing road deactivation field assessments and prescriptions;
- site level restoration objectives addressed by each of the techniques;
- descriptions of deactivation techniques supplemented by diagrams and site photographs;
- a list of field site indicators relevant to each deactivation technique;
- comments on how site conditions influence appropriate treatment prescriptions and implementation, as well as the limitations of the treatments;
- suggested tips for implementation of each treatment or technique; and
- main factors that influence treatment costs.

With the wide range of terrain, climatic conditions, access objectives and forest operations throughout the province, the methodologies that best suit the need of a specific project will also vary. Many individual operations have developed methods that work well for their particular needs with good results.

More information about implementation of restoration works is included in Section 8.

3.2 Deactivation Assessment Methodology (Field Techniques)

The objectives of field assessment for road deactivation are to:

- Assess the existing stability conditions and their potential for further deterioration;
- Evaluate the disruption to natural surface drainage paths along the road;
- Evaluate potential safety problems during project implementation;
- Mark prescriptions along the road at appropriate locations in an effective manner;
- Compile information for preparation of a report for field crews and site supervisors.

Developing road deactivation prescriptions involves previewing overview information, traversing the road and marking prescriptions in the field, and preparing a report for implementation. To develop effective road deactivation prescriptions, it is necessary to understand the terrain stability of the area (at the road and the hillslopes above and below the road), when and how the road was constructed, and applicable road deactivation techniques. This section discusses some techniques for assessing existing roads for deactivation; Section 7 contains specific information regarding the reporting of road deactivation prescriptions.

A first step is to preview material such as any overview report (see Section 2) before traversing the roads. If no report is available, review other similar overview information including air photos, detailed (1:5,000) topographic mapping, fish inventory data, and road construction information. Much of this information may be known as part of the FPC planning process. In some cases, discussing the site with the road supervisor and/or road crew may reveal some valuable first-hand information about conditions during construction.

Traverse the road carefully to assess the existing stability conditions and make prescriptions. Walking is preferred, especially in complex terrain. A hazard assessment must consider the site indicators along the road and the existing landslide, erosion, and sedimentation processes in the area for each section of the road. Typical indicators are listed in Section 3.5 for each prescription or treatment.

The traverse is usually conducted from the top end of the road, regardless of where the deactivation is planned so that no potential problems are missed or isolated. During the traverse of the road, the prescription(s) at each station must be marked to assist field crews during deactivation. For effective marking, paint can be used on suitable surfaces (such as rocks and logs) to provide highly visible prescription markings. Ribbon with markings can be used on both the road cut and outer edge of the road. For more permanent markings, metal tags can be used. These can be combined, and in some cases they are complementary. The actual marking techniques will depend on the conditions at the time of the assessment and the expected time between the traverse and implementation. For example, if the traverse is carried out during steady rain, marking stations with paint may not be feasible and ribbons and tags may be used. In cases

where bears or other wildlife are nearby, or an extended time is likely between the traverse and implementation, metal tags can preserve the field markings for longer periods. In areas with active operations, using distinctive colours and markings or standardized flagging with printing can avoid confusion with other types of layout.

Symbols for prescriptions should be specific, but not so numerous that field staff are confused. The most effective schemes use a limited number of symbols supplemented by site specific comments. The Advanced Road Deactivation Course (FCSN, 1997) provides one possible scheme. However, others exist that may be more applicable to a specific operation in specific terrain.

A person responsible for conducting the deactivation work under the WRP must meet the Forest Practices Code requirements for road deactivation. A review of the deactivation prescriptions by a qualified registered professional may be necessary. The extent of the review will depend on the existing stability conditions, the downslope/downstream resources at risk, the complexity of the prescribed deactivation, and the requirement of the Forest Practices Code. A qualified registered professional must prepare a prescription for deactivation work to reduce the likelihood of landslides in areas that have a moderate or high likelihood of landslides as determined by a terrain stability field assessment.

Other types of information may also be assessed and recorded during the field traverse. These include: the requirements for reactivation (see Section 3.4); the requirement for inspections and field reviews during the deactivation work; the expected hazard and risk to downslope/downstream resources; specific instructions to the operator at specific sites (such as sources of armour and armouring requirements); locations where benching and ramping are necessary to deal with large road fill volumes; and specific locations where safety of site personnel is a concern due to stability hazards along, or immediately above, the road.

3.3 Risk Management in Road Deactivation Prescriptions

Overall Road System Often the most critical part of a road deactivation assessment is deciding if continued access along a road is feasible, given its existing stability and potential deterioration. If the road is designated for permanent deactivation and no further access is required (and thus no further maintenance inspections are required) then the lowest practicable landslide hazard is desired after deactivation works are completed. If designated for semi-permanent deactivation, road access may allow maintenance inspections to identify and fix problems in a timely manner.

Water management and limited pullback are preferred to stabilize roads in cases where continued access is planned and practicable. Although this deactivation strategy may not be sufficient to stabilize the road in the long term, continued use of the road may be possible and preferred. Obviously, this strategy for deactivation is suitable only if it results in a tolerable landslide hazard and does not significantly increase the risk of damage to downslope and downstream resources. Where a significant or unacceptable risk exists, water management and full road fill pullback should be carried out.

When permanent deactivation with full pullback is being carried out, it is important to remember that although the cost of pulling back all road fill may be expensive, this is much less expensive than re-opening the road to fix inadequate pullback. Conceptually, different phases of road fill

pullback can be related to risk reduction as shown in Figure 3.01. For some projects carried out on western Vancouver Island, the combined cost of reactivating roads that had been previously deactivated using inadequate pullback standards, and deactivating them a second time to raise the standard of deactivation, was five to ten times the cost of the original deactivation.

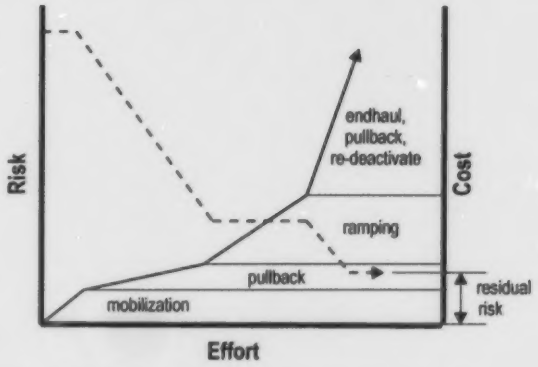


Fig. 3.01 Risk reduction in road deactivation.

The determination of tolerable residual risk following completion of road deactivation is an important component of the restoration planning and assessment process and may be the major factor influencing the eventual unit cost for any road deactivation project. Where only a low residual risk is deemed to be acceptable, the unit cost of road deactivation may be relatively high. This is especially so, for example, where a short section of high risk road occurs in a location isolated by previous deactivation and a significant portion of the project funds must be expended on reactivation. In other cases where access is reasonable and a higher level of residual risk can be tolerated, unit costs for deactivation may be significantly less. With a limited project budget, it may be more appropriate, for example, to deactivate to a less conservative level (e.g. partial rather than full pullback of fillslopes) in order to treat a greater number of sites. Any such risk management strategies, however, should be determined through consensus of all involved parties.

Site Level It is often necessary to evaluate the likely size and travel distance of a potential landslide to evaluate the landslide risk to downslope resources. In cases where the slopes below the potential initiation site are gentle or very steep, slope gradient may be the only consideration. However, for moderate to steep slopes, other factors that affect the mobility of a landslide need to be considered. These can include:

- Size and travel distance of existing landslides: Existing landslides in the area, or in nearby similar areas, can provide valuable information on the likely size and travel distance of potential landslides. Review of these existing landslides can provide valuable information on the type of landslide (material and mechanism of movement) and initiation factors in a watershed or along a road system.
- Degree of confinement: The slope morphology below the initiation site will determine if the landslide will be confined or unconfined. Confined landslides are more likely to develop into channelized debris flows and travel significantly further distances.
- Initiation Volume: Landslides that initiate with a larger volume are more likely to become larger and travel further due to their greater momentum. Conversely, smaller landslide events are much more likely to stop on relatively steep slopes. A review of the sizes of nearby landslides in similar terrain can help to elucidate this relationship.
- Stability of downslope areas and depth of material: Potential landslides above unstable slopes are more likely to be larger and travel further, since the landslide will entrain (scour) material as it passes through unstable (or marginally stable areas). For long landslides, the volume of the entrained material will often comprise most of the landslide volume. In

addition, the depth of soil downslope can provide some indication of the potential volume of material available for entrainment.

- Texture of material: Landslides containing a high proportion of fine material (sand, silt, clay) will travel further due to their lower internal friction relative to landslides containing coarse material (rock fragments, woody debris, coarse gravel, boulders).
- Water content: Landslides containing a significant amount of water and travelling as a flow are much more likely to travel further than landslides that are relatively dry. The source of the water may be from existing creeks on open slopes, within gully systems, or along existing landslide or snow avalanche tracks.

When or where appropriate, assessment of landslide hazard and consequence must be carried out by a qualified registered professional.

Risk Assessment and Management Risk is the likelihood of an event (hazard) occurring combined with the effect (consequence) that event will have on the resources in the watershed (i.e. Risk=Hazard X Consequence). The risk to resources is characterized by determining the expected adverse effects of a potential landslide to downslope/downstream resources. A method for evaluating this risk is contained in a discussion on risk assessment and management in the Forest Road Engineering Guidebook.

In road deactivation and hillslope restoration, the risk remaining following treatment is termed "residual risk" (see Figure 3.01). It may neither be practical nor cost-effective to eliminate all risk at a site (i.e. leaving some residual risk may be an acceptable option). At other locations, where the stability of the hillslope is marginal and significant residual risk remains, additional work may be justified. It may be beneficial to have a qualified registered professional review sites of residual risk while the deactivation or restoration work is in progress, so that deficiencies can be corrected in a timely and cost-effective manner.

3.4 Road Reactivation Planning

Objectives and Description: Road reactivation involves the opening of abandoned or deactivated roads on a temporary basis to carry out deactivation work. Reactivation can be challenging where the roads have been abandoned for some time and the lack of maintenance has resulted in landslides or washed out stream crossings that require significant reconstruction work for machine access.

Reactivation commonly involves improving water management along the road corridor and re-establishing the road grade. Note that since the grade is not required for hauling activities, cross-ditches and waterbars can be used to manage water in conjunction with the existing culverts. At some locations, installation of additional culverts may be necessary where sedimentation concerns exist, or in fine soils where surface rutting from vehicle traffic will occur.

At locations where landslides have adversly affected the road grade, reactivation may involve endhauling to clear landslide debris from the roadway. At locations where road fill landslides have removed part of the running width of the road, reconstruction of the subgrade is often necessary (see Section 3.6.1).

Elements of a reactivation plan may include a map and tables showing:

- the sites that pose a safety hazard during reactivation;

- road stations with prescriptions for armoured swales, cross-ditches, and waterbars;
- site specific sketches for road reconstruction, prepared/reviewed as necessary by a qualified registered professional;
- location of streams and fisheries habitat in the watershed to assist in the planning of fish salvage and sediment control measures during reactivation and deactivation;
- a list of new culverts or portable bridges required for installation during reactivation, if any.

Benefits: Unstable and/or sensitive terrain often requires more careful reactivation to prevent an increase in landslide or sedimentation hazards. The preparation of a reactivation plan during the prescription process can provide important guidance for site staff organizing and carrying out reactivation activities. Reactivation plans can also identify sites for environmental monitoring and agency notification (and approval, where appropriate). Reactivation plans may also provide an increased level of due diligence where appropriate.

Often the assessment for reactivation can be completed concurrently with deactivation prescriptions. The methodology is the same, namely noting existing features and the needed techniques for reactivation by station along the road.

Developing reactivation plans can be beneficial where there are:

- numerous reactivation problem sites and/or safety concerns;
- narrow roads with likely machine access problems;
- roads with stability or erosion problems such that careful water management during reactivation is necessary;
- overgrown roads with stability and water management concerns (structurally unsound bridges or culverts);
- roads to be kept open for more than one season to complete deactivation work (for increased due diligence);
- previously deactivated roads with moderate to heavy pullback that require re-opening.

Fig. 3.02 Reactivation of wet crossings will require notification and approval.

Fig. 3.03 Re-establishing access along a previously deactivated road.

Considerations: Road reactivation planning can vary greatly, depending on the existing conditions of the road. Where the costs of reactivation of a road (or a portion of road) may outweigh the potential benefits of deactivation, an assessment of risk to downslope and downstream resources by a qualified registered professional may be warranted. For example, road reactivation costs along road segments of previous

pullback can be extremely costly, and pose site specific safety hazards. Assessment of such a situation must consider the potential safety of the operator and crew using the road, water management along the reactivated road, the cost of the reactivation, and the expected decrease in landslide hazard as a result of improved deactivation

3.5 Deactivation Technique Descriptions

The following are typical measures carried out during deactivation. They are often combined at specific locations. For example, at a single culvert location the deactivation prescription may be "Pull Metal Culvert" and "Cross-ditch", or sections with a prescription for "Scarification" may be in conjunction with a prescription for "Insloping" for water control.

The descriptions are divided into two parts: water management (Sections 3.5.1 to 3.5.11) and road fill pullback (Sections 3.5.12 to 3.5.14). Commonly, road fill pullback will be carried out along sections of road, while water management techniques may be carried out at specific locations within or adjacent to the pullback.

Some previous discussions of road deactivation techniques have sub-divided some of the techniques listed below into more than one operation. For example, the Advanced Road Deactivation Course contains separate prescriptions for heavy pullback and gully restoration. However, in terms of the principles involved and the work carried out, these are both variations of full road fill pullback. While separating them may be beneficial for cost estimates, at times it unnecessarily complicates prescriptions.

All road deactivation practitioners are encouraged to develop clear, effective symbols and prescriptions that best address stability, sedimentation, and site productivity objectives in a particular operating area. A review by operations staff may result in valuable feedback that can make the prescriptions less ambiguous. Alternatively, some operations may have an established set of symbols and prescription formats that are appropriate for their use. The symbols and system in the Advanced Road Deactivation Course (BCFCSN, 1997) may also be used.

Coastal and Interior factors are also discussed in the prescriptions, especially with respect to the prescription indicators and cost factors for each technique. For areas where coarse rock is not available for armouring, emphasis should be placed on alternatives such as revegetation, erosion control blankets, or perhaps soil bioengineering installations.

For the following descriptions, Figure 3.04 shows some of the common terms used to denote road components and relative directions. Deactivation is most commonly carried out from the woods side to the camp side.

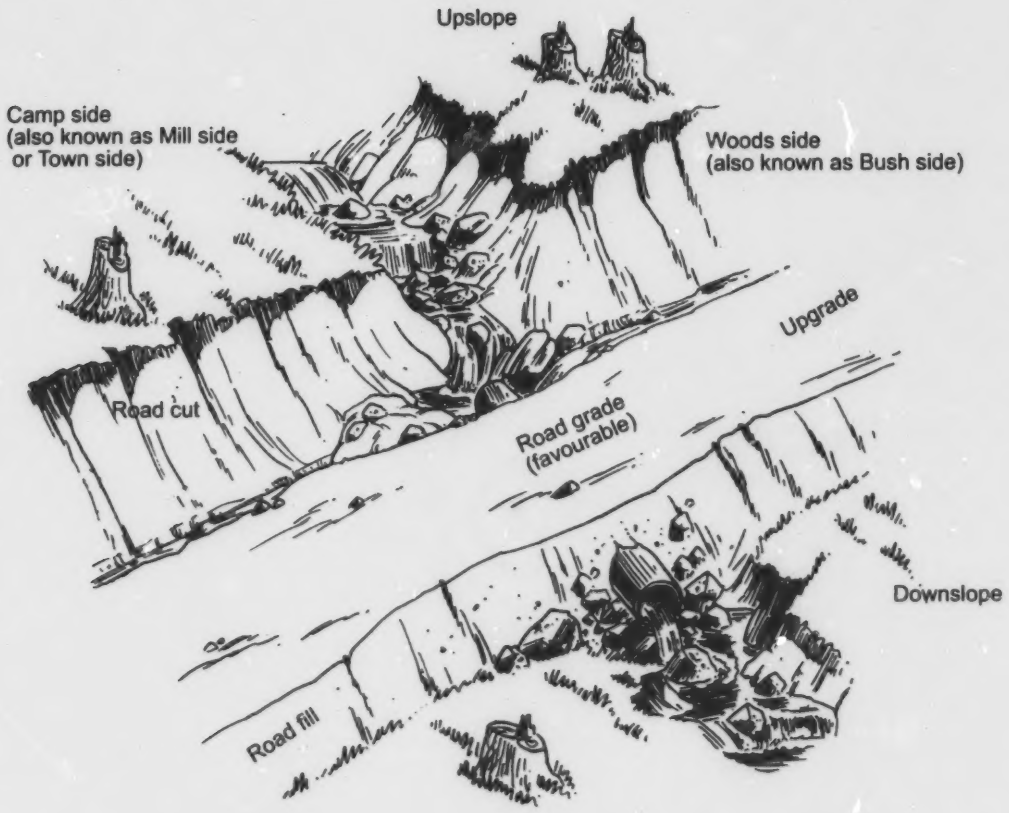


Fig. 3.04 Road orientations and naming conventions relative to a stream culvert location.

The following comments are applicable to Sections 3.5.1 to 3.5.14 on the discussion of deactivation techniques:

- ***Objectives*** - goals for the given techniques incorporating the broad goals (site level objectives) for the hillslope restoration
- ***Descriptions*** - a list of the typical features of the technique or structure
- ***Prescription Indicators*** - a list of site observations that may lead to the prescription of the technique at a given location along a road corridor
- ***Sketches*** - illustrations of the important points or features of the techniques
- ***Suggested Construction/Deactivation Tips*** - items or issues to consider during implementation of the techniques
- ***Cost Factors*** - a list of site factors that can potentially increase the cost of the technique
- ***Additional Comments*** - considerations regarding the techniques that may be important in specific circumstances

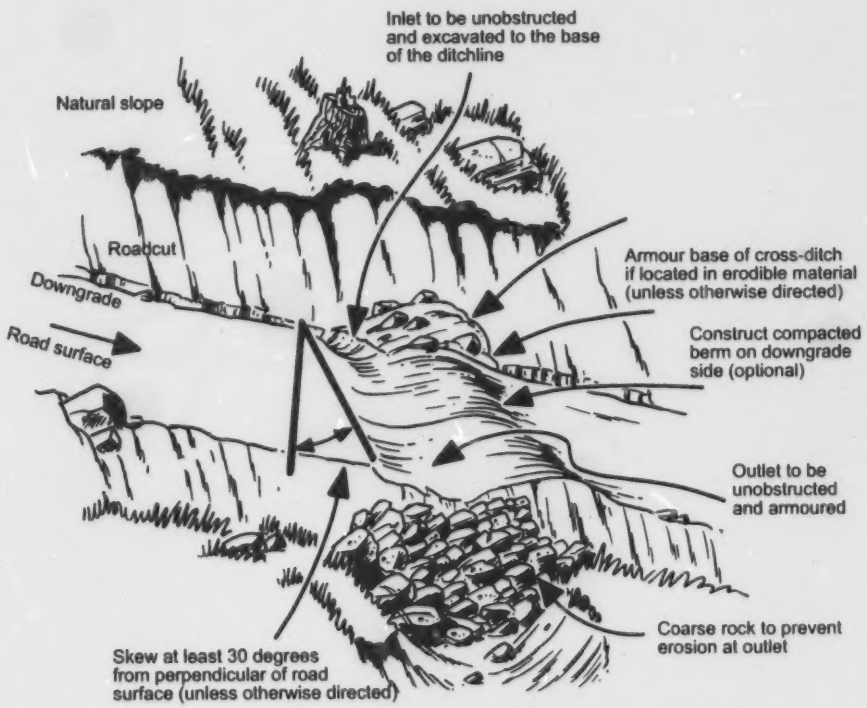
3.5.1 Cross-ditch (Road Intact)

Objective: To capture road surface and ditch line water, and route it across the road to stable, non-erodible slopes below the road. If constructed properly, cross-ditches are maintenance free.

Description: A cross-ditch is a ditch across a road excavated to a depth equal to, or greater than, the depth of the ditch at the road cut. Cross-ditches generally have a berm on the lower side, and a compacted ditch block (Figure 3.05). For areas with fine soils where vehicle access is intended, it may be better to use a broad deep swale without a berm to contain water flow (since berms will become rutted and ineffective due to ongoing traffic).

Prescription Indicators for Cross-ditches (Road Intact):

- Natural hillslope drainage path location (surface flow over road cut)
- Unstable hillslopes below road (frequent cross-ditches aid in dispersal of road drainage)[1]
- Water flow across road (road scour)
- Excessive seepage on road cut
- Relatively steep road grades
- Backup of cross-drain culverts
- Upgrade end of road sections with relatively steep grades or unretrievable unstable fills.


Inlet to be unobstructed and excavated to the base of the ditchline
Natural slope
Roadcut
Downgrade
Road surface
Armour base of cross-ditch if located in erodible material (unless otherwise directed)
Construct compacted berm on downgrade side (optional)
Outlet to be unobstructed and armoured
Coarse rock to prevent erosion at outlet
Skew at least 30 degrees from perpendicular of road surface (unless otherwise directed)

Note: Refer to Typical Road Deactivation Prescriptions Drawings in Appendix III

Fig. 3.05 Cross-ditch with road intact (no pullback).

Notes:

1. Frequent cross-ditches can be used to disperse hillslope drainage above and/or upgrade of unstable hillslopes. Consider consulting a qualified registered professional regarding the landslide hazard and risk at the site.

Suggested Construction Tips for Cross-ditches (Road Intact):

- As the outlet location is more important than the inlet to establish the gradient of the cross-ditch, start at the outlet by pulling back all woody debris and potentially unstable/erodible road fill.
- Make sure the cross-ditch inlet is deeper than the base of the existing road ditch, and the entire cross-ditch excavation is adequately sloped to resist sediment deposition. The size, depth, and shape of the cross-ditch will depend on the access requirements and the expected flows. If vehicle access is to be retained, gently slope the cross-ditch approaches. Note that on steep grades, the large berm needed to contain flow in the cross-ditch may preclude access. For steep grades an increase in skew may be necessary to reduce deposition in the cross-ditch.
- The ditch block must be relatively impermeable and non-erodible and large enough to divert expected flows into the cross-ditch. For permanent or semi-permanent deactivation, the ditch block is normally higher than the road surface. It preferably contains a mix of rock and soil, keyed into the road cut where necessary.
- Berms must be compacted and large enough to contain the expected flows, and located on the downgrade side of the cross-ditch for both favourable and adverse grades. For areas of fine soils, consider using a broad, deep swale to contain flow instead of a berm.
- Armour base of cross-ditch if erosion is expected to cause a problem for future road access. Use angular or sub-angular rock large enough for armouring against expected flows but small enough to allow for safe vehicle passage.
- Armour the outlet of the cross-ditch, unless noted in the prescriptions. Size and placement of the armour will depend on the anticipated flows and downstream consequences. Use angular rock large enough to protect exposed soil, but small enough not to divert or obstruct flows. For areas without coarse rock, suitable alternatives may include careful grading to form gentle sidewall slopes, revegetation, erosion control mats, sand bags, soil bioengineering structures, or appropriately sized and placed woody debris.

Increased Cost Factors for Cross-ditches (Road Intact):

- Gully locations (gully restoration)[1]
- Depth of road fill at outlet
- Rocky road fill or lots of large woody debris in road grade
- Road width or landing width
- Lack of suitable armour; importing required[2]
- Heavy woody debris at outlet
- Sediment control and monitoring[3]
- Strict timing constraints[3]

- Excessive road fills (large volume at outlet)
- Endhauling of excavated material necessary to maintain access

Notes:

1. Cross-ditch locations at gully crossings can involve more armouring and/or endhauling of material if excavated material cannot be placed against the road cut.
2. Importing of rock can be very expensive depending on haul distance and quarrying costs.
3. The connectivity of the stream to fish habitat or water supply areas increases the need for sediment control during cross-ditch excavation.

Additional Comments for Cross-ditches (Road Intact):

- All road fill material must be removed from the outlet area; this is particularly important for preventing landslides. Outlets of cross-ditches should not divert water onto erodible or unstable slopes.
- Larger expected flows and steeper road grades will usually require more frequent cross-ditches of greater size. Where ditches are deeply eroded, regrading of the ditch line may be needed.
- Backup cross-ditches at culvert locations (also known as "failsafes") are installed directly downgrade of the culvert location. At some locations, it may be appropriate to install these directly above or alongside the culvert; however, care must be taken to leave an adequate thickness of fill over the existing culvert. For backup cross-ditches of cross-drain culverts in erodible soils, locating the cross-ditch about 5m downgrade of the culvert may prevent a culvert washout and reduce maintenance costs. The backup cross-ditches must be large enough to handle the expected flow, and similar in design and construction to a regular cross-ditch. Backup cross-ditches must also maintain the pre-construction stream location for stream culverts.
- Cross-ditches that are located at low points in the road grade (receive water from both directions along road) need neither a ditch block nor a berm. In this case, the cross-ditch can be constructed as a broad, gentle swale.
- Careful assessment is necessary for outlet locations where significant flows are expected in the cross-ditch, and the outlet is located outside a natural channel. In these cases, the flow may cause erosion or stability problems downslope.
- Cross-ditches should be constructed to allow vehicle access commensurate with the Access Management Plan.

Fig. 3.06 Armoured cross-ditch.

Fig. 3.07 Cross-ditch as back-up to metal culvert.

3.5.2 Cross-ditch In Full Pullback

Objective: To restore the natural hillslope drainage paths to historic (pre-construction) locations along the hillslope, through road fill pullback.

Description: A cross-ditch in pullback is a ditch across the old roadbed connecting a natural hillslope drainage path (streams, gully channels, and swales with flow). Cross-ditches in pullback usually must be excavated down to natural (undisturbed), non-erodible material. The size, depth, and shape of the cross-ditch should mimic the

Fig. 3.08 Failed ditch block has resulted in water running down road grade.

nearby natural ground profiles and contours (Figure 3.09). Since no water flow along the road surface is possible in areas of road fill pullback, fewer cross-ditches are needed in pullback than for roads where no pullback is carried out.

Prescription Indicators for Cross-ditches (Road Fill Pullback):

- Road crosses natural hillslope drainage path (surface flow over road cut)
- Excessive and defined seepage areas ("piping flow" or bedrock swales)
- Upgrade or downgrade side of placed pullback material[1]
- Road is unstable or has erodible slope below and it is important to maintain dispersed drainage across the hillslope

Note:

1. Constructing a cross-ditch upgrade of pullback sections will prevent erosion along the toe of the pullback material. Constructing a cross-ditch on the downgrade side will prevent accumulation of water if the roadbed remains intact (i.e. has not been decompacted and outsloped prior to placement of pullback material) under the road fill pullback material.

Suggested Construction Tips for Cross-ditches (Road Fill Pullback):

- If armouring is needed, stockpile available rock during road fill pullback approaching the cross-ditch.
- Decompact and outslope the road surface as part of road fill pullback adjacent to the cross-ditch (see Section 3.5.14).
- Remove ballast from cross-ditch location and excavate a bench to position machine for further reach downslope. Place material on the woods side bench.

- Clear outlet of debris and road fill. Place material on the woods side bench. **Do not leave excavated material on the outside of the road if potentially unstable.**
- Excavate cross-ditch from outlet to inlet, exposing native ground for the full length of the cross-ditch. Place as much material on the woods side, and fill the bench to the top of the slope. Place armour as required; excavate as "steps" if insufficient armour is available to cover all flow areas. Do not leave oversteepened sideslopes on the cross-ditch, particularly in fine soils.
- Finish the sidewall on camp side prior to finishing cross-ditch pullback.
- At gully locations, blend slopes of pullback into existing slopes above and below the road, in and out of the gully.

Increased Cost Factors for Cross-ditches (Road Fill Pullback):

- Gully locations (gully restoration)[1]
- Depth of road fill at outlet
- Rocky road fill, or lots of large woody debris in road grade
- Road width or landing width
- Armour required; lack of available armour
- Endhauling of excavated material (cannot place material in road cut)
- Sediment control and monitoring[2]

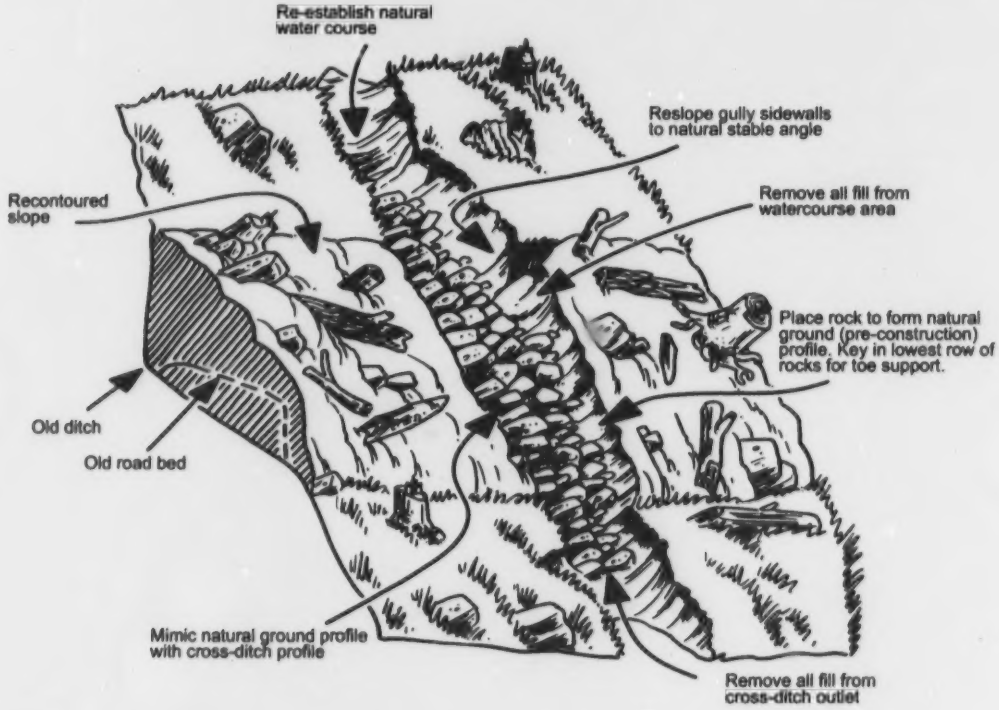

Re-establish natural water course
Reslope gully sidewalls to natural stable angle
Recontoured slope
Remove all fill from watercourse area
Place rock to form natural ground (pre-construction) profile. Key in lowest row of rocks for toe support.
Old ditch
Old road bed
Mimic natural ground profile with cross-ditch profile
Remove all fill from cross-ditch outlet

Fig. 3.09 Cross-ditch in area of road fill pullback.

- Strict timing constraints[2]
- Heavy woody debris at outlet
- Excessive road fills (large volume at outlet)

Notes:

1. Cross-ditch locations at gully crossings typically involve the removal of more road fill and less space on the bench for pullback (consider endhauling).
2. The connectivity of the cross-ditch to fish habitat or water supply areas increases the need for sediment control and adherence to timing windows and measures during cross-ditch excavation.

Additional Comments for Cross-ditches (Road Fill Pullback):

- All road fill material must be removed from the outlet area; this is particularly important for preventing landslides. Outlets of cross-ditches should not divert water onto erodible or unstable slopes.
- Armour placement (volume and size) is dependent on anticipated flows and downstream consequences. Armouring may not be needed in cases of very low flow or where the flow is not hydraulically connected to larger streams in the watershed (fish habitat or water supply areas).
- Outlets and the cross-ditch base should be armoured if the cross-ditch is located in erodible material (as compared to the natural stream channel materials). The armour must be small enough so that it does not divert flows. Armouring may not be needed if the cross-ditch is excavated into natural (undisturbed) ground, or if no sedimentation is expected.
- In pullback, skew is only necessary to line up natural hillslope drainage paths.
- For frozen roads in fine soils, cross-ditches can be difficult to maintain due to rutting from ongoing traffic. Consider armouring ditches (provided that diverted water does not cause stability problems) or using steel cattleguard-type structures as alternatives.
- Other possible prescriptions at locations where the room on the bench is needed for pullback material and coarse rock is available are trench drains (see Section 3.5.6) and blanket drains (see Section 3.5.7).
- Stream restorations at stream crossings are similar to cross-ditches but require restoring the width of the stream as well as armouring the channel. Reconstruction of streambanks should mimic upstream and downstream channel geometry and bank materials. Consider also excavating a stepped channel in non-erodible materials to reduce the flow energy if erodible materials are present downslope. These sites may warrant specific comments as part of the prescriptions. At critical sites it may be necessary to consult a specialist with expertise in stream hydrology. At sites that are expected to impact fish habitat, review by a fisheries habitat specialist is prudent.

Fig. 3.10 Cross-ditch in full road fill pullback.

Fig. 3.11 Cross-ditch within pullback but not excavated to native ground. Water has removed most of residual fill

3.5.3 Waterbars

Objective: To divert water off the road onto the fillslope to prevent erosion of road surface. Reverse waterbars direct flow off the road into the ditch.

Description: A waterbar is a shallow ditch across a road, skid trail, or backspar trail to prevent excessive flow down the road surface (or trail). Waterbars are not intended to intercept ditch lines; thus, the base of the waterbar is above the base of the ditch and no ditch block is required. Waterbars are used where a road is kept open for vehicle traffic, or where cross-ditches cannot be used (such as throughcuts). Waterbars may not include a berm if traffic along the road is expected to cause rutting and render the berms ineffective.

Prescription Indicators for Waterbars:

- Surface flow on road grade (road scour)
- Relatively steep road grades where ditch remains intact
- Throughcut with steep grades, surface erosion expected
- Upgrade of switchback to keep water off steep road grade at switchback
- Reverse waterbar where water needs to be kept off unstable road fill and can be carried in stable ditch

Suggested Construction Tips for Waterbars:

- In coarse soil and rock, place excavated material from the waterbar immediately downgrade to form a berm (as for cross-ditches); use excavator bucket to compact if road traffic is expected. In fine soil, consider using a broad swale with no berm.
- Waterbars do not have to cross the entire road surface to be effective; they must only intercept flow on the road and divert it off the road
- Waterbars must be shallow enough to allow for unimpeded vehicle access
- Consider using a herringbone pattern in throughcuts to divide the flow between the two sides. Ditching may also be necessary if the road is not sloped, or the surface is erodible.

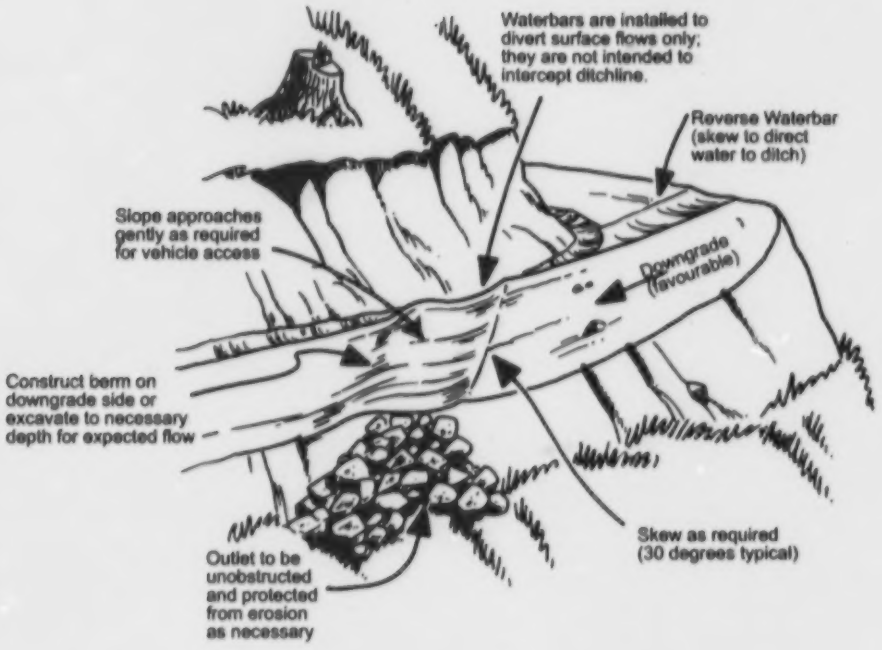

Waterbars are installed to divert surface flows only; they are not intended to intercept ditchline.
Reverse Waterbar (skew to direct water to ditch)
Slope approaches gently as required for vehicle access
Downgrade (favourable)
Construct berm on downgrade side or excavate to necessary depth for expected flow
Skew as required (30 degrees typical)
Outlet to be unobstructed and protected from erosion as necessary

Fig. 3.12 Waterbar and reverse waterbar (on right corner with favourable grade).

- Waterbars can be constructed with bulldozers or graders, depending on material type and amount of intended use of the road; however, these machines are not suited for placement of armour.
- Waterbars constructed of parallel lengths of lumber (e.g. 2x4's) embedded in the road grade may be appropriate on active roads (Figure 3.13).

Increased Cost Factors for Waterbars:

- Dense road surface materials
- Depth of road fill at outlet
- Heavy woody debris at outlet
- Road width or landing width
- Armour required; lack of available armour
- Strict timing constraints[1]
- Sediment control and monitoring[1]

Notes:

1. The connectivity of the waterbar to fish habitat or water supply areas increases the need for sediment control and adherence to timing windows and measures during waterbar excavation.

Additional Comments for Waterbars:

- Typically waterbars are skewed to better divert water off the road surface. Skew will depend on road gradient, anticipated flows, and potential erodibility of the outfall area.
- Frequency of waterbars along a road section will depend on anticipated flow on road surface
- In erodible materials, armouring of the outlet area is needed.
- In cases where the ditch is likely to plug, consider using a cross-ditch instead of a waterbar to provide greater flow capacity and more controlled water management.
- Depending on the volume of vehicle traffic and the road grade, periodic maintenance may be necessary to ensure long term effectiveness.
- For frozen roads in fine soils, waterbars can be difficult to maintain due to rutting from ongoing traffic. Consider armouring ditches (provided that diverted water does not cause stability problems) or using steel cattleguard-type structures as alternatives.

Fig. 3.13 *Waterbar constructed with parallel lengths of lumber on an active road.*

3.5.4 Metal Pipe Culvert Removal (Sediment Control)

Objective: To remove the existing stream culvert with the least amount of sedimentation possible and leave a cross-ditch. This technique is recommended where running water is present and the stream is hydraulically connected to fish habitat or community water supplies. If no water is present, no sedimentation concerns exist and cross-ditch technique can be used (Section 3.5.1 cross-ditch for road intact, 3.5.2 for cross-ditch in full pullback).

Description: Often, pipe culverts must be pulled and cross-ditches constructed where culvert maintenance is impractical or impossible (Figure 3.14). This technique can allow for culvert removal while water is present in the channel. In cases where the traffic use is expected to continue, an armoured swale or ford can be constructed following the removal of the pipe culvert (see Section 3.5.9).

Prescription Indicators for Metal Pipe Culvert Removal (Sediment Control):

- Culvert has inadequate capacity
- Damaged pipe (reduced flow capacity)
- Sediment accumulation at inlet locations (reduced flow capacity)
- Impeding fish passage; fish concerns[1]
- Improper location of culvert (disrupting hillslope drainage paths)
- Culvert in gully or creek crossing as part of permanent deactivation

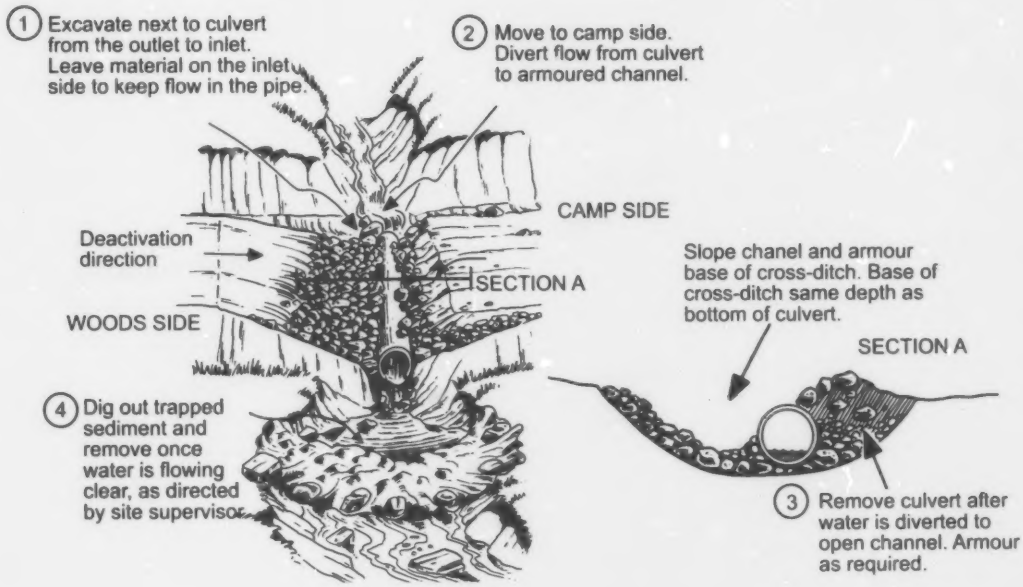

1 Excavate next to culvert from the outlet to inlet. Leave material on the inlet side to keep flow in the pipe.
2 Move to camp side. Divert flow from culvert to armoured channel.
CAMP SIDE
Deactivation direction
SECTION A
WOODS SIDE
4 Dig out trapped sediment and remove once water is flowing clear, as directed by site supervisor
Slope chanel and armour base of cross-ditch. Base of cross-ditch same depth as bottom of culvert.
SECTION A
3 Remove culvert after water is diverted to open channel. Armour as required.

Fig. 3.14 Staged removal of a metal pipe culvert where water is flowing.

Note:

1. If fish are present or downstream, designate the site for work during a timing window or have an environmental monitor on site. **Fish exclusion and salvage may be necessary prior to culvert removal.**

Suggested Construction Tips for Metal Culvert Removal (Sediment Control):

- Assess the potential adverse environmental effects at the site. Divert flows if practical. If water cannot be diverted, install sediment control downstream prior to work at the site.
- Remove road fill to expose the woods side of the culvert; then remove the road fill over the culvert. While flow is in the culvert, excavate the road fill from the downstream side to the upstream side, exposing the side of the culvert. Leave some material on the upslope side of the road to continue to divert flow into the culvert. Armour the new channel beside the culvert with rock if necessary. See Figures 3.15a to 3.15c.
- Breach the remaining road fill to route the flow into the new channel. Remove the culvert and the remaining road fill on the camp side. Armour exposed soil as required.

Increased Cost Factors for Metal Pipe Culvert Removal (Sediment Control):

- Size of culvert
- Width of road surface and length of culvert
- Amount of road fill over culvert
- Attempts to salvage the pipe[1]
- Sediment control and monitoring[2]
- Strict timing constraints[2]
- Possible fish removal[2]
- Excessive road fills (large volume at outlet)
- Heavy woody debris at outlet
- Amount of rock available for armouring[3]

Notes:

1. Salvaging metal culverts during removal can increase the time for culvert removal.
2. The connectivity of the cross-ditch to fish habitat or water supply areas increases the need for sediment and adherence to timing windows and measures control during excavation.
3. Coarse rock for armouring is much more important for pipe locations at stream crossings. Culverts that only drain ditch water may not need armouring.

Additional Comments for Metal Pipe Culvert Removal (Sediment Control):

- Each location is different and site specific approaches must be used. For complex sites, discuss options for work at the site with experienced staff and/or fisheries agencies to reduce the potential sedimentation to acceptable levels.

a)

Fig. 3.15 Metal culvert removal with sediment control.

a) Step 1 - maintain flow in pipe while excavating cross-ditch.
b) Step 2 - divert flow to newly-constructed channel.
c) Step 3 - when excavation complete, remove diversion structure.

b)

c)

- Making and keeping the site as dry as possible is often the most effective means to prevent sedimentation. Methods may include: diverting water down the ditch line until the cross-ditch is constructed and armoured provided the ditch line is not compromised; diverting streamflow using polyurethane pipe (or similar) with gravity flow; constructing a secondary cross-ditch in non-erodible materials until the main cross-ditch is complete; pumping flows around working area (if reliable pump equipment is available).
- The size, depth, and shape of the cross-ditch depends on the expected flows. Blend sidewalls of the structure to match adjacent slopes.
- If no water is present, removal of culverts in deep road fills often requires four steps: 1) remove surfacing and road fill on woods side, to expose top of culvert; 2) slope approach to a suitable grade on woods side if vehicle access is to be maintained; 3) expose and remove culvert; 4) move to camp side and complete cross-ditch excavation (slope approach to a suitable grade if vehicle access is to be maintained).
- Where coarse rock is scarce, use rock preferentially at stream crossings. Consider prompt revegetation, erosion control matting, or keeping excavated slopes as flat as possible.

3.5.5 Wood Box Culvert Removal (Sediment Control)

Objective: To remove the existing stream culvert with the least amount of sedimentation possible, and leave a cross-ditch or restored stream channel. This technique is recommended where running water is present and the stream is hydraulically connected to fish habitat or community water supplies. If no water is present, no sedimentation concerns exist and cross-ditch technique can be used (Section 3.5.1 cross ditch for road intact, 3.5.2 for cross ditch in full pullback).

Description: Often, cross-ditches are used to replace existing culverts where maintenance is impractical (or the road is designated for semi-permanent deactivation). This technique allows for culvert removal while water is present in the channel, but is not necessary if the stream is not hydraulically connected to fish habitat or water supply areas (Figure 3.16).

Prescription Indicators for Wood Box Culvert Removal (Sediment Control):

- Existing culvert with inadequate capacity to handle expected flows
- Degraded wood sills or deck; undermined wood sills; holes in ballast on deck
- Sediment accumulation at inlet locations
- Impeding fish passage; fish concerns[1]
- Improper location of culvert (disrupting hillslope drainage paths)
- Culvert in gully or creek crossing as part of permanent deactivation

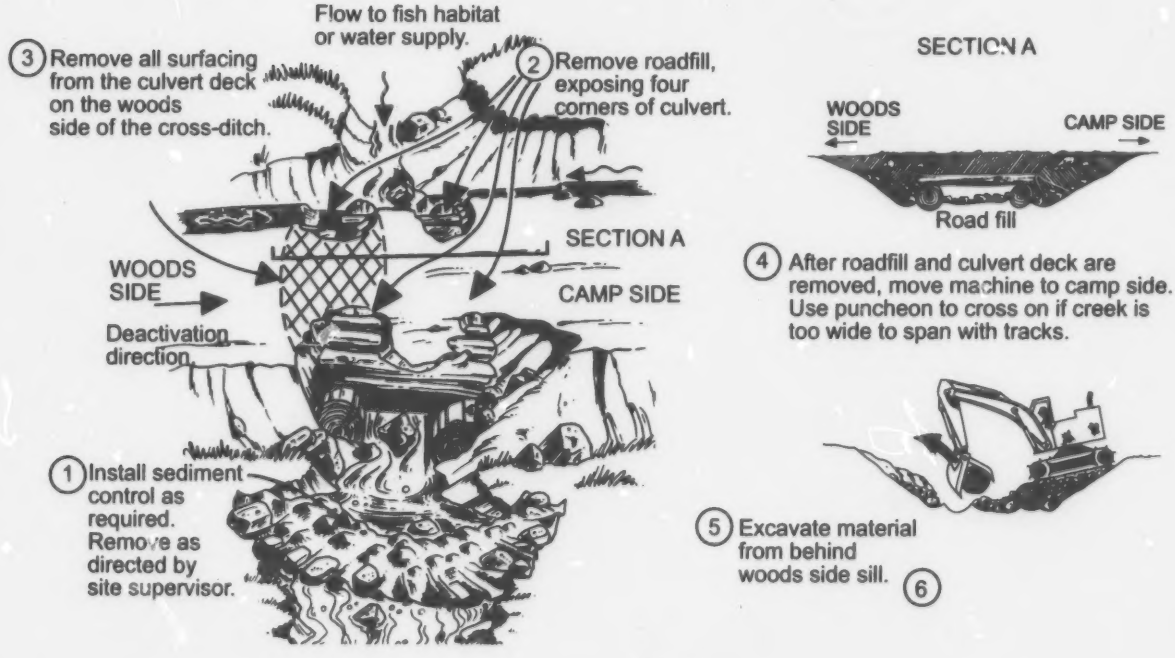

Flow to fish habitat or water supply.
3 Remove all surfacing from the culvert deck on the woods side of the cross-ditch.
2 Remove roadfill, exposing four corners of culvert.
SECTION A
WOODS SIDE
CAMP SIDE
Deactivation direction
1 Install sediment control as required. Remove as directed by site supervisor.
SECTION A
WOODS SIDE
CAMP SIDE
Road fill
4 After roadfill and culvert deck are removed, move machine to camp side. Use puncheon to cross on if creek is too wide to span with tracks.
5 Excavate material from behind woods side sill.
6

Fig. 3.16 Staged removal of a wood box culvert where water is running. It is important to follow the indicated sequence of work to minimize sedimentation.

Note:

1. If fish are present, designate the site for work during a timing window or have an environmental monitor on site. **Fish exclusion and salvage may be necessary prior to culvert removal.**

Suggested Construction Tips for Wood Box Culvert Removal (Water Present):

- Assess the potential adverse environmental effects at the site. Divert flows if practical. If water cannot be diverted, start by installing sediment control downstream of the culvert site. Consider attaching filter cloth 'diaper' below superstructure to catch sediment during de-construction.
- Excavate the road fill to expose the ends of the culvert and remove the material from the deck. Excavate road fill on the woods side to within 0.3m (1ft) of the sill log, and leave enough material to keep flow in the existing channel.
- Move to camp side of culvert. Remove the woods side sill log, pushing retained material up and out of the channel.
- Excavate camp side road fill and pull back camp side sill log, pulling soil back and away from the creek.

Increased Cost Factors for Wood Box Culvert Removal (Sediment Control):

- Size of culvert
- Width of road surface and length of culvert
- Amount of road fill over culvert
- Heavy woody debris at outlet
- Sediment control and monitoring[1]
- Strict timing constraints[1]
- Possible fish removal[1]
- Excessive road fills (large volume at outlet)
- Cable reinforcement

Fig. 3.17 Wooden culvert removal begins with fill removal from the woods side.

Notes:

1. Consider potential sediment destabilization before removing embedded large woody debris from channel.
2. The connectivity of the site to fish habitat or water supply areas increases the need for sediment control and adherence to timing windows and measures during cross-ditch excavation.

Additional Comments for Wood Box Culvert Removal (Sediment Control):

- Each location is different and site specific approaches must be used. For complex sites, discuss options for work at the site with experienced staff and/or fisheries agencies to reduce the potential sedimentation to acceptable levels.

- Methods to make the site as dry as possible may include: diverting water down the ditch line until the cross-ditch is constructed and armoured; diverting flow using polyurethane pipe (or similar) using gravity flow; constructing a secondary cross-ditch in non-erodible materials until the main cross-ditch is complete; pumping flows around working area (if reliable pump equipment is available).
- The size, depth, and shape of the final cross-ditch depends on the expected flows. Blend sidewalls of the structure to match adjacent slopes.

3.5.6 Trench Drain

Objective: To pass both surface and seepage flow across road fill pullback. Trench drains are particularly useful where all the space on the bench must be used for placement of road fill pullback.

Description: Trench drains consist of a cross-ditch that is infilled with coarse rock, to carry water from seepage areas on the road cut and/or small surface flows (Figure 3.18). Rocks used in the trench drain are usually sorted from the surrounding road fill during pullback. Trench drains differ from blanket drains in that the coarse rock extends upward to near the top of the pullback material and it is not covered with pullback material.

Prescription Indicators for Trench Drains:

Note that trench drains are only prescribed in areas of full (heavy) pullback.

- Excessive seepage zones ("piping flow" or bedrock swales)
- Road crosses relatively natural hillslope drainage path (surface flow over road cut)
- Surface flow upslope is not in an entrenched creek
- Buttressing of road cut needed at seepage area; some overland flow expected

Suggested Construction Tips for Trench Drains:

- The outlet area of the trench drain must have no erodible or unstable material.
- Excavate ditch from outlet to inlet, exposing native ground for full length. Infill with rock as ditch is excavated.

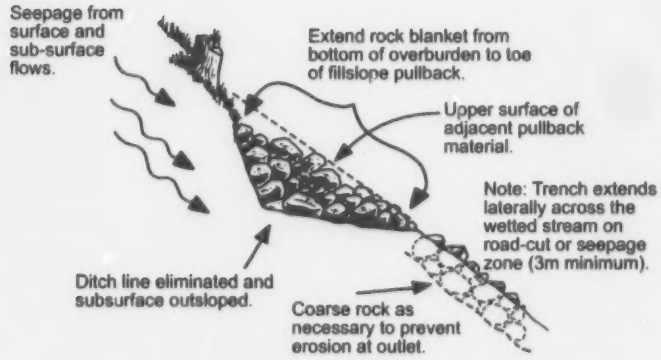

Seepage from surface and sub-surface flows.
Extend rock blanket from bottom of overburden to toe of fillslope pullback.
Upper surface of adjacent pullback material.
Note: Trench extends laterally across the wetted stream on road-cut or seepage zone (3m minimum).
Ditch line eliminated and subsurface outsloped.
Coarse rock as necessary to prevent erosion at outlet.

Fig. 3.18 Trench drain shown in cross-section through pullback.

- Trench drains must be wider than a cross-ditch to carry the same amount of flow.
- The sorting of the angular rock for the trench drain can be done while pulling back road fill. A limited amount of soil with the rock is acceptable.
- Place as much material on the woods side of the trench drain before moving to the camp side.
- Trench drains are infilled with coarse rock and built up as the road fill is pulled back.
- Double or triple handling coarse rock can help to separate fine soil from coarse rock.

Increased Cost Factors for Trench Drains:

- Amount of road fill to pull back
- Road cut height (height of seepage zone)
- Lack of availability of suitable rock[1]
- Distance to road cut (width of road)
- Endhauling of road fill pullback material[2]
- Volume of flow (determines size of armour)[3]
- Larger size of trench drain (great width and/or depth)

Notes:

1. At locations where the rock for the trench drain is not available, importing rock can substantially increase the cost.
2. Endhauling of road fill may be necessary where limited space on the bench is available for placement of road fill pullback.
3. Larger flows will require larger rock for erosion resistance; this larger rock may not be available in the road fill and may have to be imported.

Additional Comments for Trench Drains:

- If no surface flow is expected, consider using a blanket drain instead of a trench drain.
- Trench drains must not divert flow onto unstable or erodible slopes.
- Wider trench drains can help disperse the water over a larger hillslope area.
- Consider importing rock for trench drains rather than using an open cross-ditch in pullback at locations where support is needed to prevent large slumps from the road cut.

3.5.7 Blanket Drain

Objective: To disperse point seepage or subsurface flow under the road fill pullback. Blanket drains disperse flow rather than concentrate the flow at one hillslope location. Blanket drains are not intended to convey surface flow or replace open cross-ditches in areas of substantial flow.

Description: A blanket drain consists of a layer of cobbles or shot rock placed against the seepage zone in the road cut. The blanket extends down the cutslope and across the

decompacted road surface to the ground surface (Figure 3.19). Road fill is placed on top of the cobbles or shot rock, from the top of the road cut to the bottom of blanket. The blanket of shot rock does not extend to the top of the road cut, but only to the top of the seepage zone.

Prescription Indicators for Blanket Drains:

Note blanket drains are only prescribed in areas of full (heavy) pullback.

- Seepage as "piping flow"
- Very little surface flow
- Expected flows are not expected to be high, but may cause slump in pullback material
- Need to use the space on the bench for road fill pullback
- Road cut with seepage needs buttressing
- Bedrock "swales" (local depressions in bedrock) that have evidence of water flow

Suggested Construction Tips for Blanket Drains:

- The road surface must be decompacted and outsloped prior to placement of sorted angular coarse rock, otherwise the flow may be carried in the ditch line along the road.
- Retrieve all road fill material from outlet area.
- The sorting of the angular rock for the blanket can be done while pulling back road fill. A very limited amount of soil with the rock is acceptable.

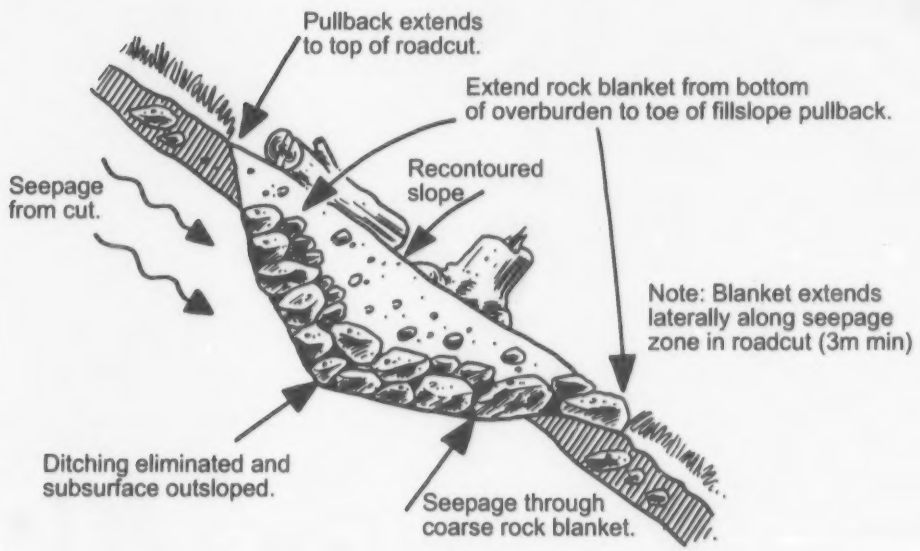

Pullback extends to top of roadcut.
Extend rock blanket from bottom of overburden to toe of fillslope pullback.
Recontoured slope
Seepage from cut.
Note: Blanket extends laterally along seepage zone in roadcut (3m min)
Ditching eliminated and subsurface outsloped.
Seepage through coarse rock blanket.

Fig. 3.19 Blanket drain shown in cross-section through pullback.

- Leaving the rock blanket exposed both above and below the pullback should be done to allow for inspection following the deactivation work.
- "Sprinkling" the rocks on the cutslope and allowing the larger rocks to roll down the longest distance will create a rock blanket at the road cut and along the decompacted road surface. Road fill pullback can then be placed on top of the blanket drain.

Increased Cost Factors for Blanket Drains:

- Larger size of blanket drain (great width and/or depth)
- Road cut height (height of seepage zone)
- Lack of availability of suitable rock[1]
- Distance to road cut (width of road)
- Endhauling of road fill material[2]

Notes:

1. At locations where the rock for the blanket drain is not available, importing rock can substantially increase the cost of blanket drains.
2. Endhauling of road fill may be necessary where limited space on the bench is available for placement of road fill pullback.

Additional Comments for Blanket Drains:

- If surface flows are expected, consider prescribing a trench drain rather than a blanket drain.
- Blanket drains will not disperse water along roads with steep road grades; check outfall location at lower end of blanket drain for stability.
- Less rock can be used if the blanket is covered with geotextile prior to placement of pullback road fill. If road fill pullback material is fine, erodible soil (silt or fine sand), use of geotextile will keep the blanket from plugging for a much longer period of time.
- If the road cut is in fine or erodible soil, the rock blanket may need to be wrapped entirely in geotextile.

3.5.8 French Drain

Objective: To divert flow along the base of the cutslope to discharge at a stable location, such as a creek or gully. French drains can be used where road fill pullback or bank sloughing may block the ditch and cause water management problems. French drains can also provide some means of water management if the road cannot be decompacted to below the ditch line depth.

Description: French drains can be used where cross-ditches are impractical, specifically: where the seepage zone is extensive in length; the retrieved road fill will be impermeable when placed against the road cut; the stability of the road fill material may be compromised if it becomes saturated. Rock for the French drain is sorted during road fill pullback of adjacent areas.

Prescription Indicators for French Drains:

Note that French drains are normally used in conjunction with road fill pullback, but sometimes they can be used for active roads with road cut instability.

- Heavy seepage or groundwater piping in road cut (could also use insloping)
- Need to keep water off unstable road fills
- Raveling or sloughing road cuts (allows for buttressing and drainage)
- Where ditch line needs to be maintained under road fill pullback material

Suggested Construction Tips for French Drains:

- The rock must be free draining; geotextile should be used between the drain rock and soil if the soil is expected to clog the spaces between the rocks.
- The size of the French drain will depend on the width and height of the seepage zone.
- French drains must not direct flow onto unstable or erodible slopes. Coarse rock should be placed at the outlet of the French drain to prevent erosion where necessary.

Increased Cost Factors for French Drains:

- Size of French drain (height, width, depth; determined by size of seepage area)
- Lack of suitable rock nearby[1]
- No availability of geotextile or slotted pipe (if needed)
- Length of French drain along road cut
- Height of road cut (if French drain is used for buttressing)
- Endhauling of road fill material[2]

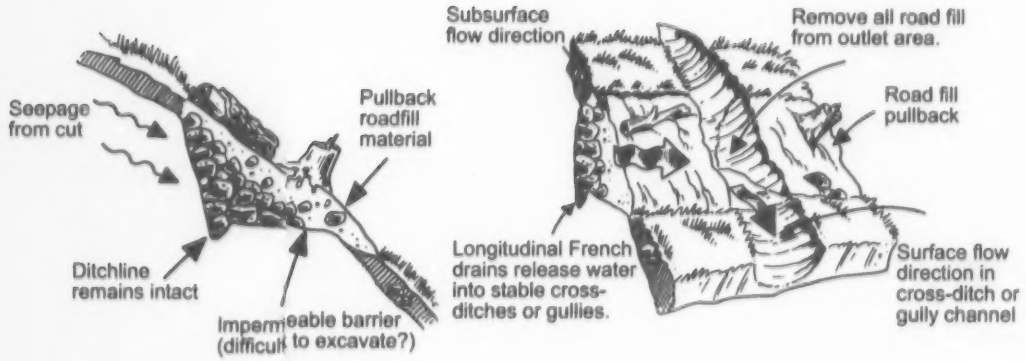
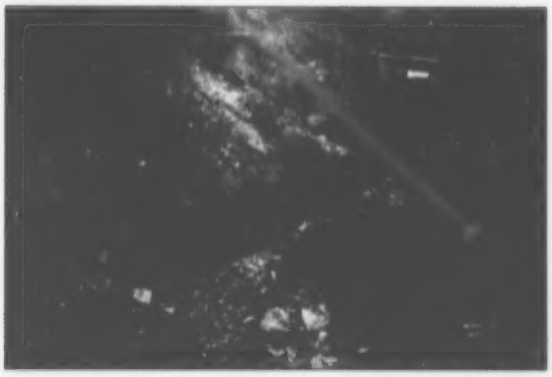

Seepage from cut
Pullback roadfill material
Ditchline remains intact
Impermeable barrier (difficult to excavate?)
Subsurface flow direction
Remove all road fill from outlet area.
Road fill pullback
Longitudinal French drains release water into stable cross-ditches or gullies.
Surface flow direction in cross-ditch or gully channel

Fig. 3.20 French drain shown in cross-section (left) and in oblique view (right).

a) Excavate trench along ditch line

b) Infill with coarse rock



c) Cover with filter fabric, then cover with fill.

Fig. 3.21 *Above, sequence of construction for French drain:*

Notes:

1. At locations where the rock for the French drain is not available, importing can substantially increase the cost.

2. Endhauling of road fill may be necessary where rock is imported and limited space on the bench is available for placement of road fill pullback.

Additional Comments for French Drains:

- In cases where steady flow must be maintained through the French drain, install a slotted pipe in the centre of the drain. This system is much more resistant to clogging than regular coarse rock.
- For active roads, lateral French drains can be installed in place of culverts to carry seepage under the road surface (use where culverts are prone to plugging).

Fig. 3.22 *French drain installed at toe of high road cut in fine-grained soil.*

3.5.9 Ford and Armoured Swale

Objective: The main purpose of a ford and armoured swale is to provide an erosion resistant and storm-proof wet crossing for motor vehicle access. A ford structure is used to cross a stream, whereas an armoured swale is constructed where a cross-ditch would normally be used. The reduction of sediment generation and sediment transport during the intended period of road use is a paramount consideration in the design of both structures. Fords are generally restricted to crossings of non-fish-bearing streams unless otherwise approved by the fisheries agencies. Armoured swales are intended to route road surface runoff, ditch water or cut bank seepage across a road where short-term vehicle access is required. Both may be constructed on access roads where culverts are not functioning (e.g. washed out or collapsed) and replacement structures not available, or where seasonal/ephemeral flows may exceed the capacity of the existing culverts during the time of road use.

Description: A ford is a dip in the road grade installed to facilitate crossing a stream (perennial or ephemeral stream flows) and is typically designed and built as a permanent feature at the time of original road construction, or during semi-permanent or permanent road deactivation (Figure 3.23). Fords are a suitable road deactivation option where existing bridges or culverts must be removed but where vehicle access must be maintained. Installation during deactivation requires excavation of all road fill to expose the original streambed. This is followed by careful placement of coarse angular rock armour. The rock armour may be graded upward to provide a more driveable surface but all material must be coarse enough to withstand mobilization during peak flows. The finished width of the ford and the approaches should mimic the adjacent natural stream channel to avoid constraining stream flow and to provide for passage of the Q100 flow. A properly designed and constructed ford should allow low flows to infiltrate though the coarse rock base and peak flows to pass over the structure with no alteration of the structure. Metal pipes may also be incorporated to aid in conveying low flows (Figure 3.25). Standard templates with site specific parameters are usually suitable for the design of most fords along existing roads. Design by a qualified registered professional may be required for large streams or for non-standard crossing situations (e.g. in close proximity to a fish-bearing reach). For further information, refer to the following updated Forest Practices Code guidebooks (in preparation at the time of publication of this handbook): *Fish Stream Crossing Guidebook* and *Forest Road Engineering Guidebook*.

An armoured swale is a dip in the road grade installed to convey seasonal/ephemeral flows across the road while continuing to provide access where it is critical to minimize sedimentation during short-term works such as road deactivation. The fill below the road grade is only partially removed and the excavated dip or swale is armoured with rock carefully placed and graded to ease vehicle access (Figures 3.24 and 3.26). An armoured swale is, therefore, intended as a temporary structure that is usually replaced with a normal cross-ditch once access is no longer required. Where flows are expected continuously during the time the road is in use, construction of a modified armoured swale using metal pipes may be preferable to further limit sedimentation. Design of an armoured swale by a qualified registered professional is not necessary given the low flow conditions and the temporary nature of this type of structure.

Prescription Indicators for Ford and Armoured Swale:

Ford

- Vehicle access required across natural drainage path (non-fish bearing stream)
- Stream flow expected during period of use
- Sufficient coarse rock available for armouring
- Existing crossing structure is required to be removed, not fully functional or unsafe
- If connected to fish habitat or water supply and stream flow is expected during the period of road use, installation of culvert pipe for modified ford[1] may be appropriate

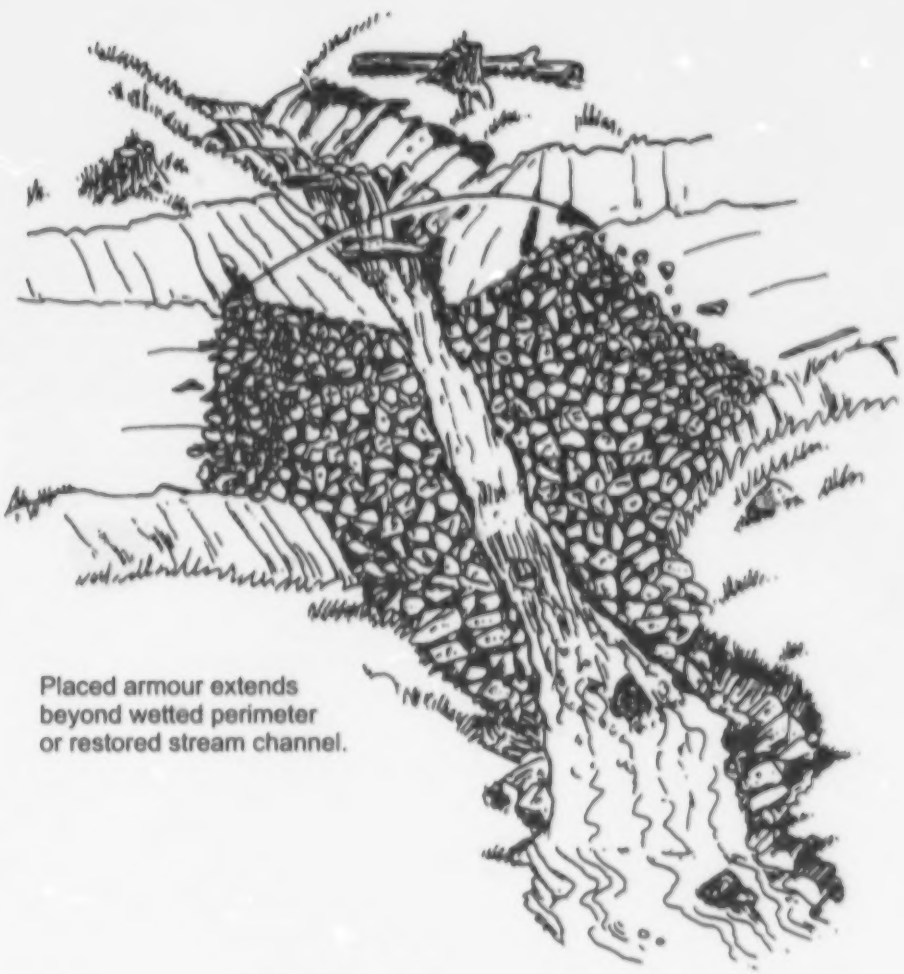


Fig. 3.23 Example of ford installed on a non-fish-bearing stream.

Armoured Swale

- Connectivity to fish habitat or water supply
- Temporary vehicle access required where flowing water from road surface, cut slope or ditchline is expected during period of use (Note: generally replaced with a non-driveable cross-ditch when access is no longer required)
- May be appropriate on snow avalanche tracks where conventional culverts are prone to blockage
- Sufficient coarse rock available for armouring
- Existing culvert is undersized, not fully functional or unsafe
- Modified armoured swale[1] may be appropriate where flow is expected and there is connectivity to fish habitat or water supply

Note:

1. Pipes should be sized to carry most of the flow, but extreme flows will still pass over the road.

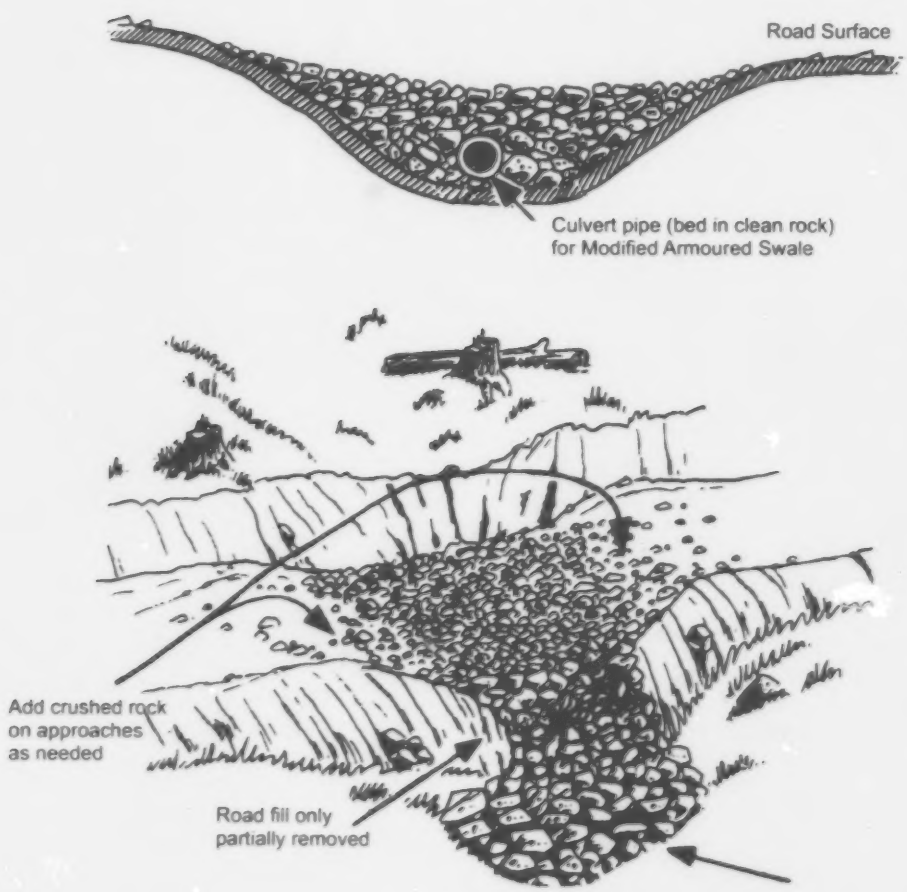


Fig. 3.24 Example of armoured swale to convey road surface, cut slope seepage and ditch water across road while maintaining vehicle access with minimal sediment generation.

Fig. 3.25 Ford modified with installation of low flow pipes.

Fig. 3.26 Armoured swale with finer material capping coarse rock base.

Suggested Construction Tips for Ford and Armoured Swale.

- Stockpile coarse, angular rock and install sediment control prior to starting work.
- Work from the downstream side of the road to the upstream side. Place rock armour concurrently with excavation. Where practicable, divert or block flow to reduce sediment transport during excavation.
- Where appropriate, make site specific recommendations (or provide a sketch) of the ford or armoured swale in the deactivation prescriptions. These recommendations can also be provided in a reactivation plan.
- Where practicable, use angular gravel on the approaches to prevent rutting and improve trafficability in wet weather.

Increased Cost Factors for Ford and Armoured Swale:

- Larger swales (width and depth)
- Excessive road fills (large volume at outlet)
- Lack of suitable armour (appropriate size and/or amount)
- Lots of woody debris in road fill
- Endhauling of excavated material (cannot place material in road cut)
- Connectivity to fish habitat or water supply may require environmental monitoring (sediment control) during excavation
- Strict timing constraints if connectivity to fish habitat or water supply
- Fish exclusion and salvage will be required for approved fords on fish-bearing streams

Additional Comments for Ford and Armoured Swale:

- Installation of a culvert pipe (or several pipes) can decrease the need for maintenance, although these may need to be inspected and cleaned in conjunction with other culverts in the area. Inspect after large rainstorms and maintain as needed.
- Heavy-walled steel pipe (used pipeline pipe) can be easily maintained and retrieved for use at another location once the structure is no longer needed.
- To construct an armoured swale where a cross-ditch is present, infill with coarse rock and maintain a swale for possible overflow.
- Large armoured swales may be suitable as longer term structures where roads cross active snow avalanche tracks and culverts will be prone to blockage.

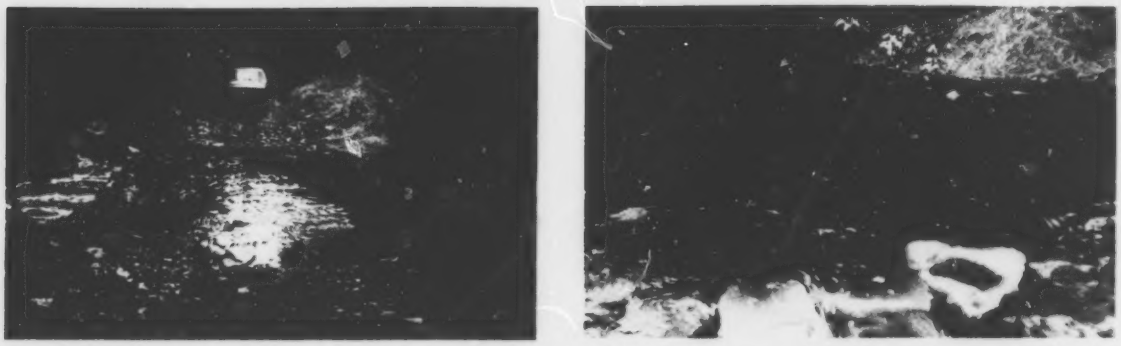


Fig. 3.27 Fords are generally restricted to non-fish-bearing streams unless otherwise approved by the fisheries agencies. Fords may be acceptable to fisheries agencies where infrequent vehicle traffic is anticipated provided certain criteria are met. In this example, the ford has been constructed on a low gradient fish stream using large rock slabs to form a 'pavement' across the wetted perimeter of the stream (left photo). At low flows, fry access is possible between the rock slabs, while at high flows juvenile and adult fish can pass over the structure (right). At such installations, gates or other approved methods of restricting motor vehicle access may be necessary to protect fish and fish habitat.

3.5.10 Insloping/Outsloping

Objective: To control water without the use of ditches or cross-ditches. Insloping directs the water into the road cut while outsloping directs the water across the road to the fillslope (or road shoulder).

Description: Insloping is the sloping (reshaping) of the road surface to direct road surface water toward the road cut and away from unstable or erodible road fill materials. Outsloping is the sloping (reshaping) of the road surface to direct water across the road and onto the road fill in a dispersed fashion (Figure 3.28). Insloping may not be effective on significant grades (6% or greater) as the water runs down the wheel ruts. Outsloping is is best applied where the road grade is gentle to flat.

Prescription Indicators for Insloping/Outsloping:

- Maintain access during reactivation
- Narrow road - no room for ditch
- Insloping: non-erodible material in road cut
- Outsloping: ditch line cannot be maintained due to ravelling road cut
- Outsloping: flat to gentle grades; concern about local instability with cross-ditch outlets and waterbar outlets; continuous cutslope seepage

Suggested Construction Tips for Insloping/Outsloping:

- The slope of the road surface laterally must be greater than the grade of the road to effectively direct water.
- Insloping/outsloping may not be suitable for areas with fine grained soil where rutting due to vehicle traffic is expected. Traffic rutting can reduce or eliminate the effectiveness of insloping and outsloping. In these cases, consider importing road surfacing material and compacting adequately to resist rutting.

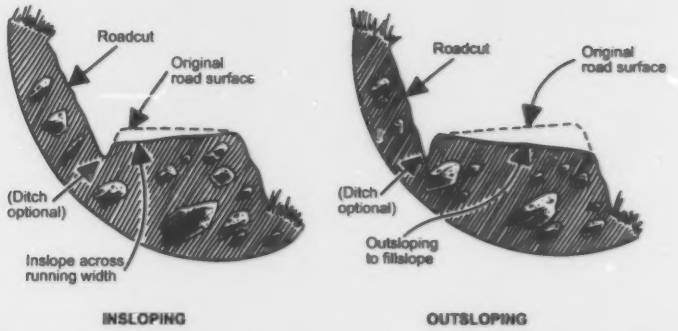


Fig. 3.28 *Cross-sections showing insloping and outsloping to control road drainage. Preservation of the ditch is dependent on factors such as the frequency of maintenance and the stability of the road cut.*

Increased Cost Factors for Insloping/Outsloping:

- Wide roads or landings
- Improper equipment[1]
- Need to maintain a driveable surface
- Endhauling of excavated material
- Dense road surface materials
- Importing suitable road surfacing material

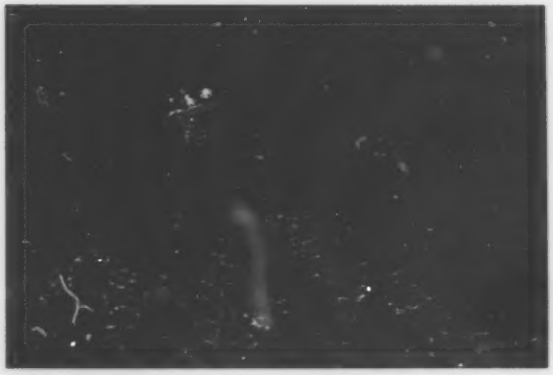


Fig 3.29 *Example of outsloped road.*

Notes:

1. Insloping and outsloping over longer distances can be completed effectively using a grader or a bulldozer; using an excavator can substantially increase costs.

Additional Comments for Insloping/Outsloping:

- A ditch is optional for insloping/outsloping; however, a ditch can prevent some of the water from reaching the outsloped road surface and may improve trafficability. Where no maintenance will be carried out, the ditch line should be removed or filled in during outsloping.
- Outsloping may present a safety hazard on snow-covered roads where traffic use continues through the winter.
- Insloping and outsloping may require constant, careful re-grading in areas of heavy truck traffic.

3.5.11 Berm Pullback

Objective: To restore natural hillslope drainage paths where road maintenance activities have left a berm or windrow on the outer edge (or inner edge) of the road. Larger berms may also be pulled back to reduce the weight on the outside edge of the road and/or for silvicultural reasons.

Description: Berms or windrows are often the result of road grading and road reconstruction activities. On older roads (constructed with a grade shovel), berms may be present on the outer edge of the road (see Figure 3.30). Pullback of berms allows water to pass over the shoulder of the road. Pullback of berms may also be carried out in conjunction with outsloping and/or cross-ditching to restore hillslope drainage paths.

Prescription Indicators for Berm Pullback:

- Water diversion along road by berm on outer edge (or inner edge) of road
- Water entrenched into road surface
- Large continuous berm with no vegetation
- Weight of large berms may initiate landslide in road fill, and larger landslide downslope

Suggested Construction Tips for Berm Pullback:

- Determine spoil site requirements and location(s) for berm material.

Cost Factors: The following factors will tend to increase the costs of berm pullback

- Berm size (volume of material)
- Machine requirements[1]
- Removal of large second growth on berm
- Double handling of material on wide roads
- Endhauling of material (cannot be placed on road grade or on fillslopes below road)
- Sediment control

Note:

1. Size of berm will dictate the most efficient machine type and size for pullback.

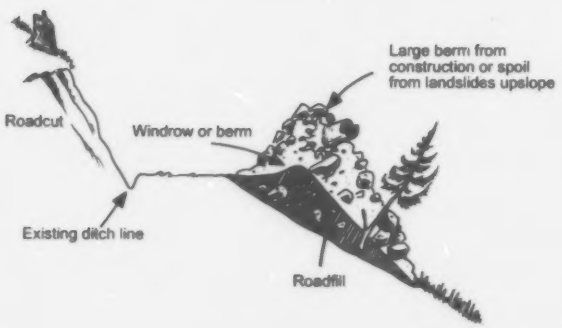


Fig. 3.30 Cross-section showing road fill and berm prior to pullback.

Additional Comments for Berm Pullback:

- Consider natural drainage paths along with pulling of berm. May want to prescribe cross-ditches, outsloping, insloping, (or ditching for active roads) to best control drainage.
- If the berm is to be breached locally to discharge road drainage, rather than pulled back, assess the stability and erosion potential at the outlet areas.

3.5.12 Scarification

Objective: Scarification (also known as Silvicultural Fluffing) is carried out to increase the site productivity of compacted road surfaces.

Description: Scarification is the breaking up of the road surface to a minimum depth of approximately 400 mm or 16-20 inches. Where practical, scatter organics and woody debris on scarified road surface.

Prescription Indicators: Any of the following site indicators may require scarification.

- Compacted road surface
- Road fill stable, no pullback needed
- Site productivity for conifers may be improved
- Road is stable and no further access is needed

Suggested Construction Tips for Scarification:

- Scarification is more important for road surfaces where the materials are well graded, and/or high traffic volumes have compacted the road surface.
- Consider consulting with a silviculture forester to determine the benefit of scarification relative to planned tree species and site index parameters along the road.
- Evaluate the effective compaction in both the traveled and untraveled parts of the road running width.
- Mixing soil with rock during scarification may also increase site productivity

Increased Cost Factors for Scarification:

- Road or landing width
- Water management (insloping, etc)
- Road ballast depth (depth of compaction)
- Significant amount of large woody debris
- Road age (extent of compaction)
- Numerous large non-commercial trees growing on road

Additional Comments for Scarification:

- Consider the existing site productivity along the road prior to prescribing scarification; existing conditions may be in an acceptable state of recovery.
- Consult with silviculture forester to determine expected improvement in site productivity relative to existing conditions (road grade and adjacent stand).

3.5.13 Partial Road Fill Pullback (Access Maintained)

Objective: To reduce stability problems along the road yet maintain vehicle access. Partial road fill pullback is carried out when full restoration is not needed for immediate stability, or road access is needed at some future date.

Description: Partial road fill pullback retrieves the currently or imminently unstable portions of the road fill and leaves those portions with no evidence of immediate instability intact. Retrieved road fill is placed tight to the road cut with organic soil and woody debris on top to promote revegetation (see Figure 3.31). Endhauling of material is necessary when the unstable volumes of road fill exceed the available room in the ditch line. Carrying out partial road fill pullback may not reduce the landslide hazard to the fullest extent possible.

Prescription Indicators for Partial Road Fill Pullback: Any of these site indicators often justifies partial pullback on a road where access is to be maintained.

- Road fills with a large proportion of shot rock[1] (pullback of all material is not necessary)
- Small road fills over high landslide hazard areas
- Full road fill pullback not needed for immediate stability
- Newer roads where some root strength is retained, and short term access is needed[2]

Notes:

1. For road fills with a large proportion of rock, some material can be left on slopes below the grade and full road fill pullback may not be needed.
2. Inspection should be carried out, and full road fill pullback may be needed at a later date

Suggested Construction Tips for Partial Road Fill Pullback:

- Decompaction is not needed for partial road fill pullback where access will be maintained.
- Pullback currently unstable road fill. Endhauling may be necessary if placement of unstable road fill will result in loss of road running width.
- Place retrieved road fill material in the following order:

1. Road surface materials and shot rock (non-organic soils)
2. Organic soils and fine grained soil
3. Woody debris and other vegetation (organics)

Increased Cost Factors for Partial Road Fill Pullback:

- Location (gully versus open slope)[1]
- Size of existing vegetation[2]
- Road fill comprised of difficult materials (large woody debris, or large rocks in road fill)
- Improper machine size (match size of machine to volumes of pullback)
- Road fill volume and/or long fillslope length (P distance)

- Excavation of saturated material[3]
- Maintenance inspections to confirm water management controls are functioning well and there are no slope stability concerns
- Wide road or landing
- May need to re-mobilize equipment at some future time to carry out full road fill pullback to address long-term stability concerns

Notes:

1. Often pullback in gully areas requires more endhaul or movement of material out of the gully.
2. Sizeable trees on the road fill may not be large enough to stabilize the road fill, but may still increase the time and/or machine size requirements for pullback.
3. Saturated material is more difficult to keep on the bench and maintain the required angle on road fill pullback (angle of repose). Some endhaul may be necessary.

Additional Comments for Partial Road Fill Pullback:

- Cross-ditches must be constructed immediately upgrade of the start of road fill pullback to prevent erosion of the retrieved road fill.
- Consider constructing cross-ditches immediately downgrade of the retrieved road fill also, especially if the ditch line is intact under the road fill pullback.
- All natural watercourses must remain free of pullback material. Accommodate water flow in these areas using cross-ditches, trench drains, or in some cases, French drains.

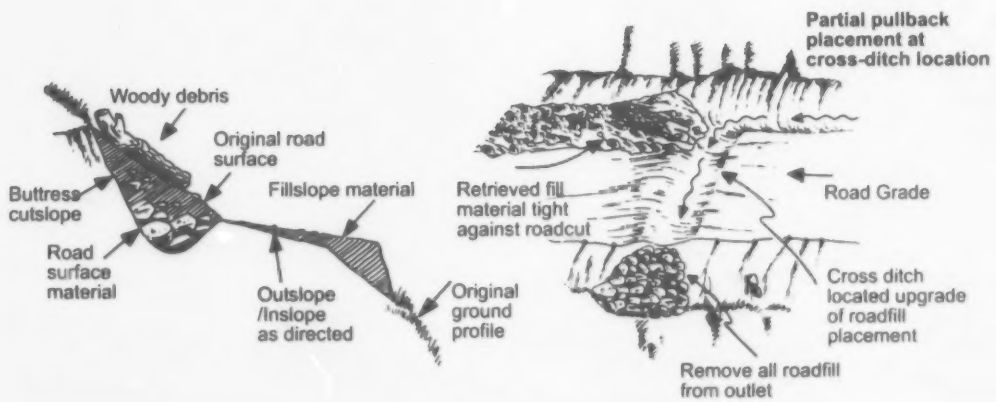


Fig. 3.31 Cross-section showing partial road fill pullback (left) and view showing cross-ditch for diversion of flow away from placed pullback material (right).

- Endhauling may not be necessary when continued access is not planned; most material can be placed directly on the bench.
- If access is required, endhaul requirements can be lessened by placing removed brush and woody debris back onto the pulled back fillslope. This material will aid in short-term erosion control as well as enhance soil nutrients. It may be cost-effective to complete all required pullback for a road section, then replace the brush and woody debris in conjunction with installation of water management structures.
- Do not inslope or outslope the road unless specified. Consider decompaction if no access will be needed following deactivation.
- In some cases, wood box culverts can be left in place if the openings are adequately sized and they are backed up by adequate cross-ditches.
- If access will not be maintained, consider how stability of the road will deteriorate over time before concluding that full road fill pullback is not necessary.
- At some sites, partial pullback combined with appropriate water management may be the most cost-effective means of reducing landslide risk to tolerable levels for the intended period of continued vehicle access, but future full roadfill pullback may be needed on steeper slopes to reduce the landslide hazard to tolerable levels.

3.5.14 Full Road Fill Pullback

Objective: To retrieve all potentially unstable sidecast road fill and place it tight against the road cut. Full road fill pullback reduces the road fill landslide hazard to the fullest extent possible. Typically, no access or only limited access for foot or ATV traffic is possible after full road fill pullback has been carried out.

Description: Full road fill pullback, also known as "re-contouring" or "de-building", is the de-construction of the road subgrade to restore the original hillslope profile and contours (Figure 3.34). Full road fill pullback typically involves decompaction and removal of the road surface to establish safe working areas and increase the downslope reach of the excavator. Where very long and deep road fills are present, benching and/or ramping may be needed to adequately retrieve and place all the road fill present (Figure 3.36). In cases where all of the retrieved material cannot be placed on a stable bench, endhauling may be needed. Woody debris is randomly scattered on the surface of the pullback material, promoting revegetation and inhibiting deer movement to reduce browse on seedlings.

Decompaction may be necessary for full road fill pullback (Figure 3.34) especially in areas of heavy seepage. Decompaction is the breaking up of road fill materials (ballast and subgrade) to a depth equal to, or greater than, the depth of the ditch and removing the material. The decompacted surface is outsloped, to provide better downslope reach and promote water flow across the road under the pullback material. Decompaction of the road fill can also define the width of the natural bench so that a safe working limit for the excavator can be established.

Prescription Indicators for Full Road Fill Pullback: Any of these site observations is often an indicator that full road fill pullback is needed. Consider both the landslide hazard and the risk to downslope/downstream resources when deciding whether full road fill pullback is needed.

- Landslides from road fill in adjacent areas
- Large retrogressive landslides in road cut
- Tension cracks in road (not settlement cracks)[1]
- Sidecast construction with high road cut
- Pistol-butted trees or jackstrawed (tilted) trees on road fill
- Narrow roads and high cutslopes on steep slopes
- Road fill supported by stumps and other woody debris; abundant large woody debris in road fill
- Road fill settlement above steep, unstable areas; repeated filling and grading of road fill areas

Notes:

1. Settlement from decomposing wood may not be a stability problem on gentle to flat hillslopes, but may be a safety problem for vehicle traffic or hauling activities.

Suggested Construction Tips for Full Road Fill Pullback:

- Walk site to evaluate safety concerns prior to starting road fill pullback. **If a safe approach is not apparent, ask for help.**
- Prior to starting pullback at the station, visualize the ground profile and contours above and below the road.
- As appropriate, decompact and remove the road surface to a depth below the ditch line. Sitting the excavator on the lowered (decompacted) surface will extend the effective reach of the excavator during pullback. Note that decompaction may not be possible in areas where a portion of the road bench is blasted into solid bedrock. In this case, complete fill retrieval may not be possible. Consider using a log to push any residual unstable fill downslope. It may be preferable to unload this material in a controlled manner during dry conditions, rather than have it fail during wet conditions.
- Retrieve all fill to expose native material.
- Place road fill material tight to the road cut. During road fill pullback in rocky materials, releasing material above the slope and letting the rocks roll down to the bench can often create a blanket drain.
- Place retrieved road fill material in the following order; see sketch below.
    - Road surface materials and shot rock (non-organic soils)
    - Organic soils and fine grained soil
    - Woody debris and other vegetation (organics)
- Benching-Ramping may be necessary in areas where unstable road fill is present beyond the reach of the excavator. An example of the steps for benching and ramping is shown in Figure 3.36.
- Step 1 establishes a bench that is wider and lower than the existing road grade, increasing machine reach. Additional benching may be necessary to retrieve all unstable fill. **Benching must only be done by experienced operators, only into native ground with an escape route available at all times.**

Fig. 3.32 Site indicators for full road fill pullback include fill supported by woody debris.

Fig. 3.33 Presence of tension fractures and/or slumping of road shoulder may also justify full road fill pullback

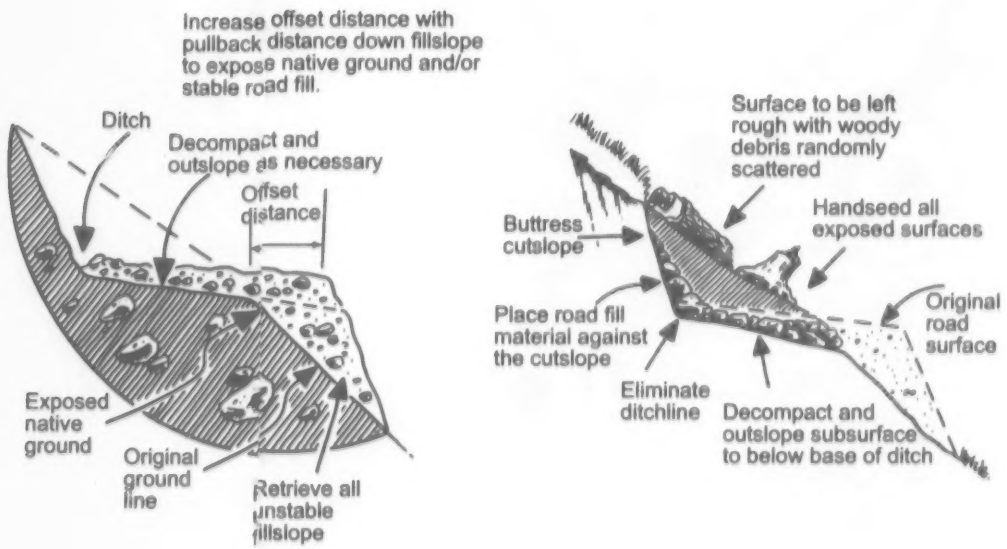
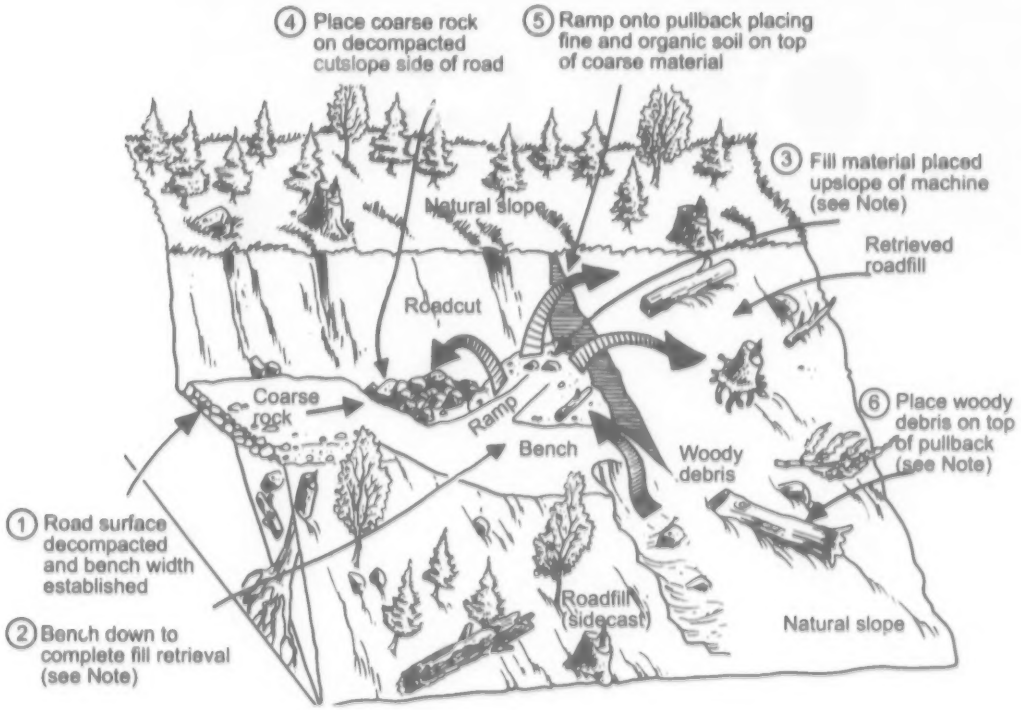

Increase offset distance with pullback distance down fillslope to expose native ground and/or stable road fill.
Ditch
Decompact and outslope as necessary
Offset distance
Exposed native ground
Original ground line
Retrieve all unstable fillslope
Surface to be left rough with woody debris randomly scattered
Handseed all exposed surfaces
Buttress cutslope
Place road fill material against the cutslope
Original road surface
Eliminate ditchline
Decompact and outslope subsurface to below base of ditch

Fig. 3.34 Cross-sections showing road prior to pullback (left) and completed pullback with full retrieval of fill (right).

Fig. 3.35 Full sidecast pullback before (left) and after (right).


4 Place coarse rock on decompacted cutslope side of road
5 Ramp onto pullback placing fine and organic soil on top of coarse material
3 Fill material placed upslope of machine (see Note)
Natural slope
Retrieved roadfill
Roadcut
Coarse rock
Ramp
Bench
Woody debris
6 Place woody debris on top of pullback (see Note)
1 Road surface decompacted and bench width established
2 Bench down to complete fill retrieval (see Note)
Roadfill (sidecast)
Natural slope

Notes:

1. Numbers refer to recommended sequence for machine positioning and road fill pullback.
2. Never position the tracks of the machine parallel or at right angles to the centerline of the road. Always work 20° to 45° off the road centerline.
3. For areas with less road fill and/or wide roads, ramping may not be necessary if the material can be sorted during pullback and placed appropriately.

Fig. 3.36 View showing process of benching and ramping to complete full road fill pullback and sort the retrieved material as it is placed against the road cut.

- Step 2 retrieves material from the road fill and places it in an intermediate position. After moving the excavator up the ramp, material can then be sorted and placed at specific positions on the bench (Steps 3 to 5).
- To create a blanket drain with road fill containing large rock, sort the material by sprinkling it onto the slope to segregate the larger rocks from the fine soil (see Section 3.5.7).
- The bench and ramp sections should generally be kept short to ensure the completion of each section. The bench and ramp should form a "Y" in plan view. The length of the bench will depend on bench width, road fill volumes to be retrieved, and fillslope length.
- Additional benching is not necessary for road fills that can be retrieved from the decompacted bench.
- Woody debris should be scattered with random orientations (Step 6) to reduce deer browse on seedlings and increase the number of productive microsites.

Increased Cost Factors for Full Road Fill Pullback:

- Location (gully versus open slope)[1]
- Size of adjacent vegetation[2]
- Large road fill volume and/or long fillslope length (P distance)

Fig. 3.37 Two hoes working in tandem to complete full road fill pullback. Hoe on right is benching down to retrieve fill, while hoe on left is ramping up to place fill tight against cutslope. Note placement of woody debris on top of recontoured slope.

- Excavation of saturated material[3]
- Wide road or landing (unless material does not have to be placed tight to road cut)
- Undersized machine (larger machines can be more efficient)
- Landslide material on road grade[4]

Notes:

1. Often pullback in gully areas requires more endhaul or multiple handling of material.
2. Sizeable trees on the road fill may not be large enough to stabilize the road fill, but may still increase the time and/or machine size requirements for pullback.

3. Saturated material is more difficult to keep on the bench and maintain the required angle on the placed road fill pullback (angle of repose). Some endhaul may be necessary.

4. Endhauling of material is often necessary where space for placement of road fill pullback material is limited.

Additional Comments for Full Road Fill Pullback:

- All road fill must be retrieved from gully channels, gully headwalls, and creek channels. Consider removing all road fill from open slope depressions and wet hillslope areas.
- Cross-ditches, trench drains, blanket drains, and in some cases French drains must be used to restore the natural hillslope drainage paths concurrent with full road fill pullback.
- The ditch line must be eliminated using decompaction for roads with moderate to steep grades, otherwise the ditch will continue to divert water.

Fig. 3.38 *Access for foot or ATV traffic may be possible after full road fill pullback provided all potentially unstable road fill is pulled back in high hazard areas.*

- In areas with road cut instability, full road fill pullback can also partially support the road cut and reduce the landslide hazard.
- Placing road fill during wet conditions may result in small slumps in the retrieved road fill, or problems retaining retrieved material on the bench. **Consider suspending operations during extremely wet conditions for safety and/or environmental reasons.**
- Assess the stability of the site continually during pullback in terms of machine stability and safety of the operator. Change the positioning of the machine or suspend operations in wet weather as required. In extreme cases, consider modifying the work plan as appropriate to ensure safety.
- If foot access is required following deactivation, a walking path can be left by leaving a gap at the top of the brush and woody debris placed on the retrieved pullback.

3.6 Prescription Considerations

In addition to the deactivation techniques described in Section 3.5, some important considerations merit discussion. These include special sites along the road that must be assessed during deactivation (or in some cases, reactivation). Often these sites will require assessment by very experienced site personnel in conjunction with a qualified registered professional.

3.6.1 Special Sites

Road Reconstruction

Objective: To achieve temporary access for deactivation activities by reconstructing the road subgrade and/or drainage system as necessary. For example, reconstruction of the road subgrade is necessary at locations where a landslide has reduced the running width of the road, making access unsafe and/or impossible.

Description: Road reconstruction involves altering the road grade and/or alignment to achieve the necessary running width. There are three general options for reconstruction:

1) Excavating into the road cut to increase the running width. This method is suitable when the road cut materials can be excavated, (i.e. don't require blasting), and the slopes immediately above the road are not steep (otherwise large volumes of material will be created).

2) Excavating to lower the road grade to achieve the necessary running width. This method is suitable when the material below the road is stable.

3) Constructing retaining structures on the outside of the road to increase the strength of the road fill. This method can be used where excavating into the road cut is not possible due to cost or stability concerns, and excavation to lower the road grade is not possible due to cost concerns or because non-rippable bedrock comprises the road bench.

The three methods of road reconstruction can be used together. For example, it is possible to combine 1) and 2) to move the road centreline both into the slope and lower the grade to reduce the amount of excavation in some cases.

Benefits: The benefits of road reconstruction are access for machinery and increased safety during access. At some locations, such as gully crossings, excavation into the road cut and/or lowering the road grade (followed by subsequent endhauling) are often needed during road fill pullback regardless.

Considerations: Road reconstruction is practical often when part of the road fill is stable. If the entire running surface of the road is unstable, simply moving the road centreline into the road cut may not provide for a stable running width.

Costs for reconstruction can be considerable, particularly if blasting, hauling coarse rock, constructing engineering structures such as a retaining wall, or using geosynthetic-reinforced road fill is required.

Endhauling

Objective: Endhauling is required at specific locations during reactivation and deactivation to ensure that enough room is available on the road bench to avoid placing landslide debris or road fill pullback on unstable slopes.

Description: Endhauling involves moving material along the road corridor to a stable location. Endhauling is commonly required in four cases where unstable slopes are located below the road and road fill cannot be placed in the immediate area:

F2

1) Landslide material (or material from the road cut) is present on the road grade and blocks access, or occurs along a section requiring road fill pullback (assuming that all of the space on the bench is needed for placement of pullback material);

2) Road cuts with inadequate space to accomodate the expected volumes to be retrieved (where material was moved laterally along the road during construction). This is common for bulldozer construction in steep terrain and/or gully areas.

3) Road reconstruction requires excavation and the material cannot be placed safely on the road grade nor on steep/unstable slopes immediately below the road;

4) Road fill material that is saturated and will not maintain a slope steep enough to remain on the bench following pullback.

Wise and Horel (1998) discuss endhauling during reactivation and deactivation, as well as some of the criteria for selecting spoil sites.

Benefits: Endhauling during reactivation can ensure that the maximum amount of room on the bench is available in areas of full road fill pullback. For deactivation, some endhauling during full road fill pullback may help to restore the hillslope contour and profile, reducing the likelihood that road fill will remain on unstable hillslope areas and cause landslides in the future.

Considerations: Endhauling increases the costs of reactivation and/or deactivation. The extent of the increase is dependent on the working room at the site, the distance to spoil sites, and the size and quantity of the spoil sites available. This increased cost must be

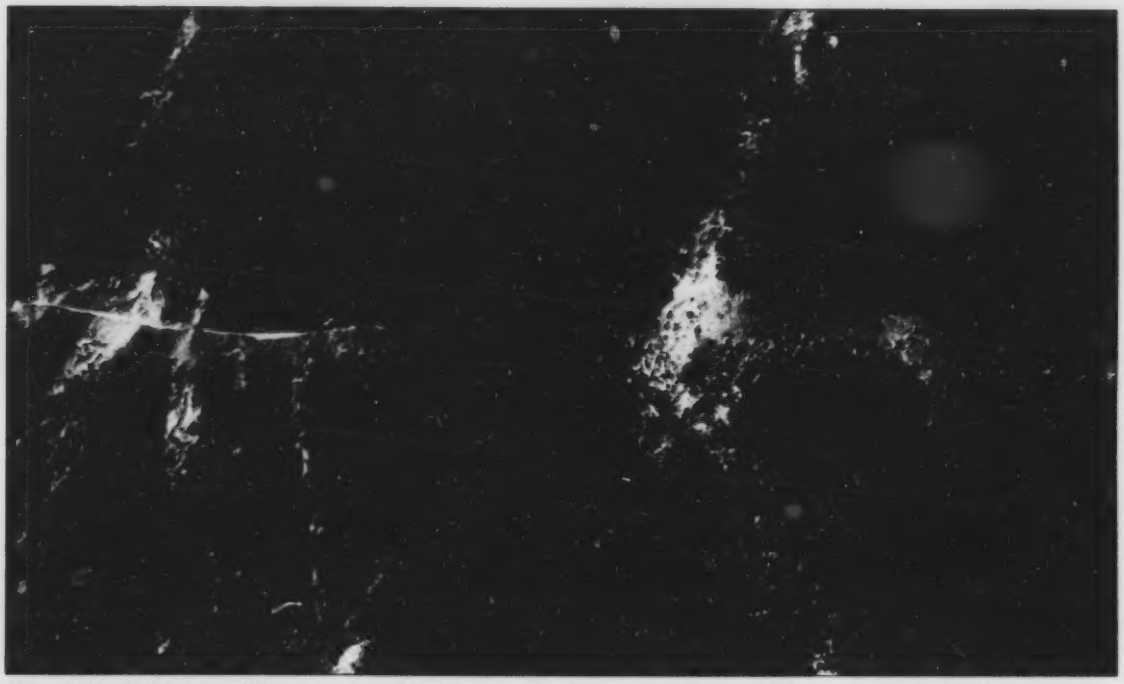


Fig. 3.39 *Fillslope pullback and endhauling required to remove excess fill volumes in and adjacent to a gully.*

considered and evaluated against the increased hazard associated with not endhauling material. In some cases, endhauling material can improve the efficiency of pullback operations. In steep, mountainous terrain identifying suitable endhaul spoil sites can be challenging. Where necessary, deactivation prescriptions should identify all possible endhaul spoil locations in steep terrain. It may be possible at some locations where the road is to be kept open to reduce endhaul costs by using some of the spoil to build up the road grade in the immediate area.

Gully Restoration

Objective: To restore the gully channel to its historic (pre-construction) conditions and decrease the landslide hazard along the road approaches on the sidewall of the gully.

Description: Gully restoration typically involves pulling all of the material out of the gully channel during deactivation activities, and is carried out during full road fill pullback. The size, depth, and shape of the pullback must mimic the natural ground profiles and contours of the gully system above and below the road. Armouring of the gully channel at the road location, and endhauling of excess road fill material is often required. Similar techniques can also be used for entrenched creeks. Refer to the Gully Assessment Procedure Guidebook for detailed information on the deactivation of roads at gully crossings.

Benefits: Gully restoration is the most viable means of stabilizing gully systems and reducing the landslide hazard to historic (pre-construction) levels. Since even small debris slides into gully systems can develop into larger debris flows, gully restoration decreases the risk to downslope and downstream resources.

Considerations: Some sidecast material on gully sidewalls can be difficult to retrieve. This occurs frequently in gully areas where bulldozers were used for construction and bedrock prevents benching down to retrieve the material. Also, large woody debris in gully channels can be difficult to excavate due to its interlocking nature. In these cases, the decision to remove it during deactivation should consider the gully processes and the consequence of leaving the woody debris in place (see Section 5.3.1).

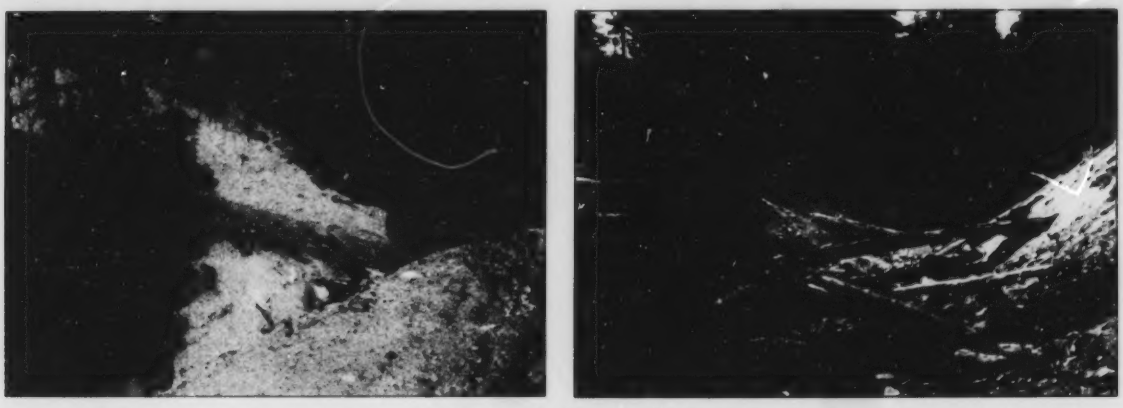


Fig. 3.40 *Restored gully at road crossing in Merritt Forest District. Some large woody debris is left to provide obstacles to cattle, act as sediment traps and to provide nutrients and shade for seedlings.*

Blasting of Road Fills for Deactivation

Objective: To stabilize road fills at isolated locations where access for excavators is neither possible nor cost effective.

Description: Blasting is intended to remove the weight of the road fill and disperse the fill onto the slopes below the road. Generally, blasting is applicable at locations where intermittent or isolated stability concerns exist along a road. Muir et al. (1999) discuss a case study where blasting was used to stabilize a road fill for deactivation.

Benefits: Blasting can be used to deactivate isolated, high risk sections of road where no other means is viable.

Considerations: Blasting may not be applicable at locations where the road requires a large, continuous length of pullback, or where the blasting may pose a risk to houses, highways or other infrastructure. In addition, blasting may not be possible at locations where the road fill contains a large proportion of woody debris that would prevent adequate confinement of the blast and reduce its effectiveness. Blasting should only be carried out in dry weather and potential fire hazard should be considered. A series of blasts may be needed to stabilize large road fills at locations where the explosives cannot be placed deep into the road fill.

Continued Future Access

Objective: To incorporate continued future access requirements into road deactivation prescriptions to provide for continued road use and/or minimize the cost associated with reactivating the road at a later date.

Description: Future access is often required for forest operations or for other users once deactivation is completed. In these cases, some minor modifications can be made to the deactivation prescriptions to decrease the future access costs. For water management, these modifications include:

- Prescribing armoured swales (or modified armoured swales) as part of deactivation;
- Leaving the road bed intact under road fill pullback to enable future access once the fill is removed to a suitable location;
- Leaving culverts in place, backed up with cross-ditches;
- Stockpiling coarse rock for later use as riprap at portable bridge sites;
- Partial road fill pullback combined with outsloping, insloping, leaving a running width suitable for access.

Benefits: Modifying deactivation prescriptions to permit future access is a low cost approach to allow for re-opening roads following deactivation. Where access is maintained, the road can be easily inspected and repaired as necessary.

Considerations: Modifying the deactivation techniques to decrease costs for future access should only be carried out where such modifications will not significantly decrease the effectiveness of the road deactivation techniques. At some locations, it may be appropriate to require inspection/monitoring of a road over a specific period of time.

Planning for deactivation during road design and construction

Purpose: Planning for deactivation during the design and construction of forest roads can decrease the costs and improve the effectiveness of deactivation. For winter roads, using deactivation measures during road construction can significantly decrease maintenance costs.

Description: The design and construction of newer roads represents an opportunity to decrease the costs associated with deactivation, and improve its effectiveness (Horel, 1998). Examples include stockpiling coarse rock for use at armoured swale and cross-ditch locations, limiting the length of road fills so that benching is not needed during road fill pullback, and stockpiling organic soils for later use on road fill pullback or subgrade.

Benefits: For winter roads, planning for deactivation during the construction of the road can decrease the amount of maintenance and deactivation needed during the summer months, when the roads are generally impassable. On other roads, planning for deactivation during construction can allow for the road to be deactivated at less cost using smaller excavators.

Considerations: During the road design process, it is often possible to make a decision on the need for road fill pullback along a branch road. Where the design calls for minimal road fill, marginally stable locations may only require water management rather than road fill pullback following harvesting activities.

For winter roads, carrying out deactivation immediately following hauling is important to reduce the potential for erosion from vehicle traffic.

Range Management Issues

Objective: Road deactivation in range areas requires due consideration of the access requirements and the potential consequences of disrupted road access to ranchers including removal of traditional watering sites for livestock.

Description: Where road access is important for range management, deactivation should be carried out to provide required access and maintain the existing drainage patterns that may be linked to range watering systems where practicable.

Benefits: Identifying where range management may be affected by deactivation may preclude conflicts over road access and provide for better management of water resources in an area.

Considerations: Roadside ditches can sometimes act as water sources for cattle. Restoring natural drainage paths in these situations may result in removal of these sources, forcing the livestock to use existing creeks for a water source. This may result in environmental damage to these creeks. Construction of small watering ponds at appropriate road sites in conjunction with deactivation may alleviate this concern. Fencing may also decrease the potential environmental damage from livestock where sensitive slopes are at risk.

Knapweed and other noxious weeds need to be considered during road deactivation assessment. Such plants are common along many old logging roads and deactivation may

spread these through machine travel or seed disturbance. Consultation with a Range Agrologist may be warranted to minimize the likelihood of spreading these problem weeds. Scheduling of deactivation work outside seed maturity time should also be considered.

3.7 Surface Erosion and Sediment Control

Control of surface erosion and subsequent sediment transport during road deactivation is paramount where there is direct or indirect connectivity to aquatic habitat and/or aquatic resources. As erosion control has a generally higher level of effectiveness than sediment control, the primary goals should be to first minimize potentially damaging erosion of the disturbed sites; and second, limit the transport of sediment from these sites. While some amount of soil disturbance is inevitable from most road deactivation activities, the ultimate aim should be to re-establish natural rates of erosion and sedimentation as soon as possible following works.

Reduction of erosion during deactivation is possible through careful planning of operations and through awareness during operations. Confining sensitive operations to periods of dry weather, minimizing traffic through these areas, and selecting equipment that will create less disturbance (e.g. rubber tired or rubber tracked machinery) are options that should be considered where practical. Compliance with local rainfall shutdown guidelines is mandatory and care should be exercised in this regard (i.e. accurate precipitation measurements should be taken at appropriate intervals, antecedent moisture and soil saturation should be monitored, rain-on-snow events considered). For deactivation of water crossings (e.g. culvert removals, stream restorations), temporary diversion and/or impoundment of stream flow can reduce the exposure of disturbed soil to flowing water, however, prior agency approval may be required.

Once soil disturbance has occurred, erosion protection should be implemented as soon as possible. Revegetation by seeding with a grass and legume mix, as described in Section 3.8, is generally the most appropriate treatment for reducing erosion. Grading of disturbed slopes to a stable angle will help to facilitate establishment of the vegetation cover. For newly created slopes (e.g. pulled back fillslopes, slopes comprised of retrieved road fill), erosion may be reduced and revegetation aided by striating the soil with the excavator to form a series of small terraces. On gently sloping sites, placing a layer of straw or similar material in conjunction with the seeding can be a cost-effective means of providing short-term benefit in reducing rain splash erosion until the vegetation establishes. A similar effect may be gained by replacing the brush on pulled back fillslopes. Placement of properly sized rock riprap is effective in reducing runoff velocities and associated erosion in stream channels and ditches. In certain situations the use of alternative, more costly, revegetation treatments may be warranted (e.g. erosion control revegetation mats, bonded fibre matrix products).

Once sediment has been mobilized by erosion, a number of sediment control measures can be used to minimize sediment transport. Each has its own advantages and limitations. Regardless of the measures taken, it is critical that all of the necessary materials, tools and personnel be on hand as the work proceeds. A certain amount of routine maintenance is also necessary to ensure optimal performance. The main sediment control techniques that are applicable in road deactivation include:

Silt Fencing is appropriate for installation immediately below the toe of the slope to prevent mobilized sediment from becoming entrained in flowing water. The bottom of the woven geotextile material should be keyed into the soil or buried with drain rock for maximum effect (Figure 3.42). Suitable locations for installation of silt fence include the base of pulled back fill slopes, along stream banks or ditch sidewalls (above the high water mark) and around recently spoiled material. Silt fencing should be carefully removed and disposed of following adequate establishment of vegetation cover. Silt fencing is not effective when installed in flowing water and may lead to an increase in bank erosion. Use of certain types of erosion control revegetation mats (ECRM's) may be an alternative to conventional silt fencing. When laid down and anchored as narrow strips (i.e. 0.5 to 1.0 m wide) in place of silt fence they can act as effective sediment traps. They can also be seeded through and left in place. Sod strips may be used to provide a similar benefit.

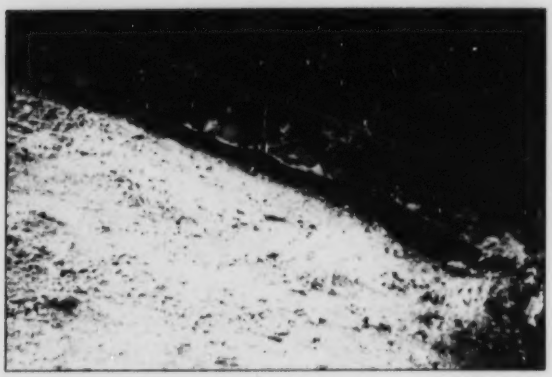


Fig 3.41 *Silt fence installed at toe of pulled back fillslope.*

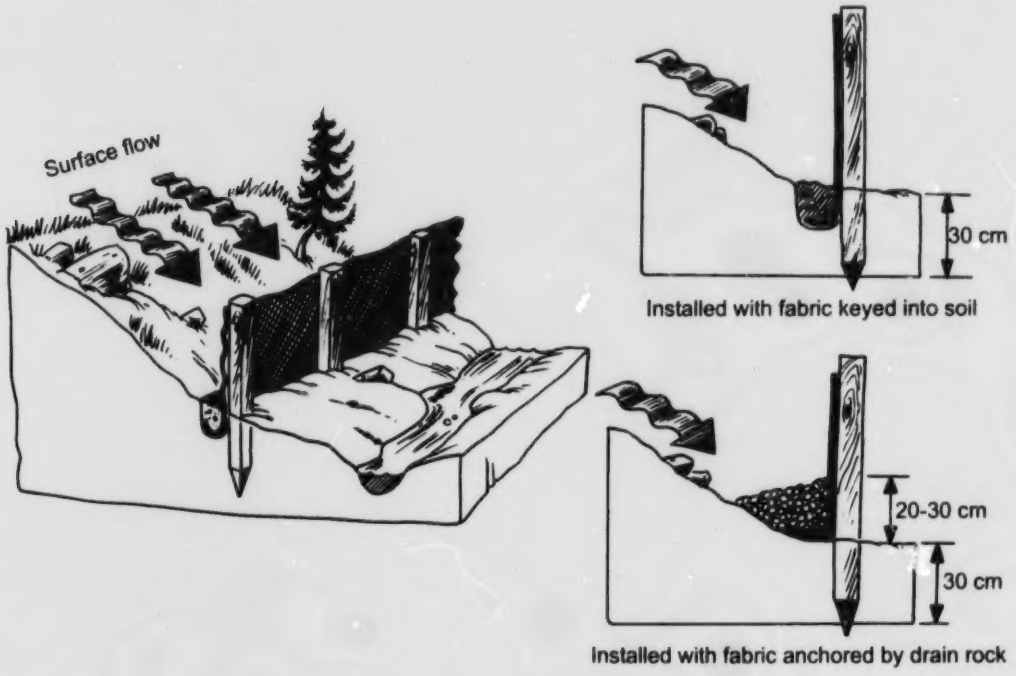


Fig.3.42 *Proper silt fence installation (modified after Fifield, 1997).*

Check Dams are intended to both reduce erosion of a channel by reducing flow velocity and to provide for retention of sediment in the channel. They are generally appropriate for channels or ditches where relatively low flows are anticipated in the short-term following deactivation works. For Coastal sites, sediment retention is usually intended to be short-term with subsequent sediment release over an extended period. For some Interior sites, check dams may provide a long-term benefit in reducing erosion. Installation of rock check dams may be useful across cross-ditches constructed within fillslope pullback zones where full armouring of the channel is not practicable due to lack of rock. Check dams may be constructed solely of rock or in combination with materials such as straw bales and filter cloth (N.B. construction with straw bales alone is not recommended). For sediment retention by check dams built with rock only, rock diameter will depend largely on expected flow volumes. Where adequate size rock is not available, sandbags may be a cost-effective alternative for construction of temporary check dams. Proper construction requires that the sides of the structure be 15 cm to 45 cm higher than the centre to allow water to flow over the structure rather than around it (Figure 3.44). Soil bioengineering structures such as live silt fences and live gully breaks also act as check dams and may be appropriate for low flow sites.

Fig. 3.43 *Check dam constructed of hay bales wrapped in filter fabric for temporary sediment retention.*

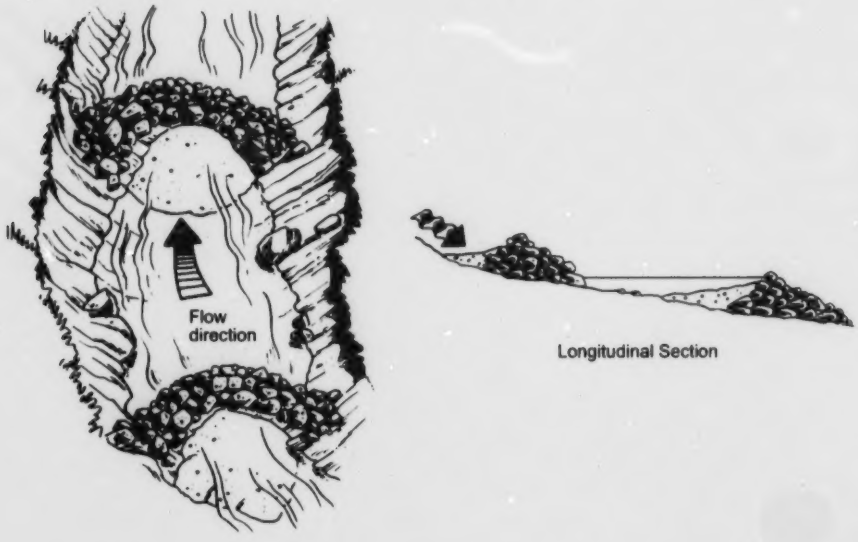


Fig. 3.44 *Proper check dam construction (modified after Fifield, 1997).*

Riprap involves the placement of rock riprap (armouring) to reduce the velocity and erosive effect of flowing water and, like check dams, can provide temporary sediment retention. Riprap is commonly placed along ditch lines and at the inlets and outlets of cross-drain structures. Rock size is dependent on anticipated flow volumes. Angular rock is generally best suited for use as riprap.

***Fig. 3.45** Open bottom arched culvert used for temporary access across a fish stream.*

Sediment Catchment Basins are intended to provide for longer-term retention of fine sediment that settles from suspension slowly. They should be constructed in or lined with non-erodible material and must be large enough to provide sufficient time for the fine sediment to settle. Basins generally require periodic cleaning and appropriate disposal of material. For this reason they may not be suitable for situations where regular maintenance is not carried out.

Stream Crossing Techniques are used to limit sedimentation caused during crossing of streams. These may include conducting activities during periods of low flows, diverting any flows around the work site (via pumps and impoundments), and minimizing both the removal of existing vegetation and the duration of the activities. For control of sediment mobilized during the work, check dams constructed with a filter fabric can be effective for sediment removal. Depending on conditions, a series of these structures may be necessary to provide sufficient benefit. Installation of silt fencing may be appropriate along disturbed streambanks until revegetation or placement of riprap has occurred. The temporary use of open bottom, arched culverts may be acceptable to fisheries agencies where repeated crossing of a fish stream is necessary during for the period of deactivation. Such structures are intended to allow for continued fish passage and may be reusable (Figure 3.45).

3.8 Revegetation

Revegetation of deactivated roads is essential to reduce erosion and aid in restoring productivity to the road area. This section presents information on the revegetation of deactivated roads, landings and associated soil disturbances to reduce the risk of erosion and associated impacts to downstream resources. General information on revegetation presented in this section is also applicable to revegetation of gullies and landslides. Effective revegetation can reduce erosion rates by as much as 100 times (Wischmeier and Smith, 1965), however, improper revegetation can result in the establishment of a dense cover of seeded species on the disturbed sites leading to successional stagnation (Kimmins, 1987) and the loss of site productivity.

3.8.1 Grass and Legume Seeding

Seeding is the most common and usually the most cost-effective means of treating deactivated roads to prevent erosion and should be considered even where some level of vehicle access will be possible following deactivation. In most cases, a seed mix

composed of agronomic species is used and is applied dry either with or without fertilizer. For some areas, it may be desirable to select a seed mix that will not encourage grazing by livestock. A discussion of the principles used for selection of appropriate seed species is contained in Section 4.3.3.

Fig. 3.46 *Results of handseeding on pulled back road.*

Dry broadcast seeding immediately following the deactivation works is the most common means of applying seed, whether by hand using a hand-held "cyclone" type seeder or by machine such as a vehicle-mounted spreader or a helicopter-slung bucket. A major problem with most seeding projects has been the tendency to over-apply the seed. Mixed grass and legume seed should not be applied at rates that exceed 50 kg/ha. Higher rates will generally result in severe seedling competition to the eventual detriment of the established stand and planted or invading woody species.

Fertilizer may or may not be applied with the seed at the time of seeding. In most cases, where deactivated roads are seeded using agronomic species, a light application of fertilizer will assist in initial establishment and growth. Unless there are indications to the contrary, a high analysis, balanced fertilizer containing all of the essential macro-nutrients, Nitrogen, Phosphorus and Potassium (N, P & K) applied at a rate of from 100 to 300 kg/ha will be suitable for most sites throughout the Province. At these rates of application, detrimental effects to water quality or fish habitat are unlikely. It is important to remember that the objective of most forest land revegetation programs is not to establish a permanent stand of grasses and legumes but to encourage the eventual invasion of the site by native woody species.

If handseeding is carried out, the product (seed and fertilizer) should be transported to the site as work is progressing to avoid having to pack material to the work area if vehicle access has been removed. The amount of product required per lineal metre of road will depend on the width of the road prism requiring revegetation.

Hydroseeding, where seed, fertilizer, mulch and tackifier are applied in a slurry with water, can be used for revegetation of deactivated roads, although it is more costly and, for freshly deactivated roads, often not as effective as dryseeding. As with broadcast seeding, seed application rates should not exceed 50 kg/ha. Hydroseeding is discussed in greater detail in Section 4.3.3.

3.8.2 Woody Species Establishment

Establishment of woody species on disturbed forest sites, whether through natural invasion or planting, is essential for restoration of the site. Pioneering species such as alder, willow and, in some cases, lodgepole pine and Douglas fir are important early colonizers of disturbed sites. These species prepare the site for later successional forest species such as spruce, cedar and hemlock. The establishment of native woody species is discussed in greater detail in Section 4.3.5.

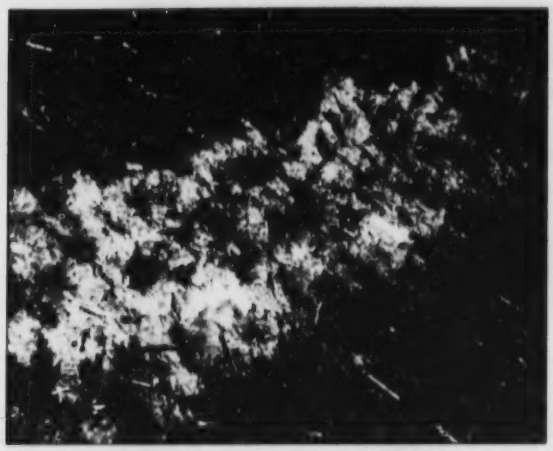


Fig. 3.47 *Salvaging of conifers and deciduous vegetation along pulled back road, Prince George Forest District. Survival of conifers is 10%; survival of deciduous vegetation is 80%.*

Conifers can be established on deactivated roads and other disturbed forest sites, although unless the soils of the site are similar to those of the surrounding block, the growth will generally be slower than in the adjacent stand. In general, disturbed forest sites tend to be droughty and have reduced available nutrients compared to the adjacent stands. Tree species selected for planting should be suited to conditions that are one step drier and one step more oligotrophic (nutrient poor) than would be predicted for the prevailing soil moisture and nutrient regime classes for the corresponding adjacent stand. A qualified forester or biologist should review the selection of tree species for planting on any disturbed forest sites.

3.8.3 Special Revegetation Considerations

Soil bioengineering (see Section 6) as well as a variety of specialized revegetation techniques can be helpful in the treatment of difficult sites. In most cases, discussions with a revegetation specialist are useful when dealing with difficult sites.

4.0 Landslide Rehabilitation Assessments and Prescriptions

4.1 Introduction

Rehabilitation of landslides or disturbed slopes is recommended at active sites featuring characteristics such as failing headscarps or sidescarps, or where there is mobile slide debris. Rehabilitation is also encouraged where continuing erosion and sediment transport is adversely affecting resources. Landslide rehabilitation may be conducted as part of watershed restoration or as an operational obligation to address environmental liability.

The intent of this section is to:

- Review the assessment procedure for landslides or disturbed slopes
- Discuss how the physical and biological site information obtained from the assessment is used to develop a preliminary treatment prescription
- Describe and illustrate the main treatment types currently employed
- Provide practical advice for prescription development and implementation
- Discuss treatment costs and treatment cost factors

Classification of slope failures in the forest environment are described in Section 1.3. Figure 4.01 shows a landslide in the forest environment.

Landslides comprise a range of mass wasting events from rock falls, to rotational slumps, to debris slides and flows. Debris slides and flows are typically shallow failures where the failure plane is within surficial material and, therefore, have the greatest potential for rehabilitation mainly through revegetation treatments. Other types of disturbed slopes that may be amenable to rehabilitation, especially in the Interior, include road cut (see Figure 4.02) and road fillslopes and streambanks. Bedrock failures and deep-seated rotational failures require special considerations and are beyond the scope of this section.

Fig. 4.01 *Landslide in forest environment.*

An idealized landslide is shown in Figure 4.03 with the main zones shown. Typical slope gradients are also shown but these will be strongly influenced by site specific factors such as soil type and soil water content. The initiation zone is generally marked by a steep unstable headscarp area that is scoured to bedrock or to compact subsoil. The transport or scour zone is mainly characterized by mobilization and transport of existing material to varying depths. Minor deposition may occur locally where breaks in slope occur. The deposition zone is characterized by deposition of soil,

woody debris and rock and may be linear in nature or spread laterally to form a fan.

The main objectives of rehabilitation for landslides and disturbed slopes are to:

- Stabilize the site to reduce the potential for additional mass-wasting;
- Minimize offsite sediment delivery;
- Initiate and accelerate the natural rehabilitation process; and
- Provide greater safety for downslope activities.

Fig. 4.02 Unstable road cutslope

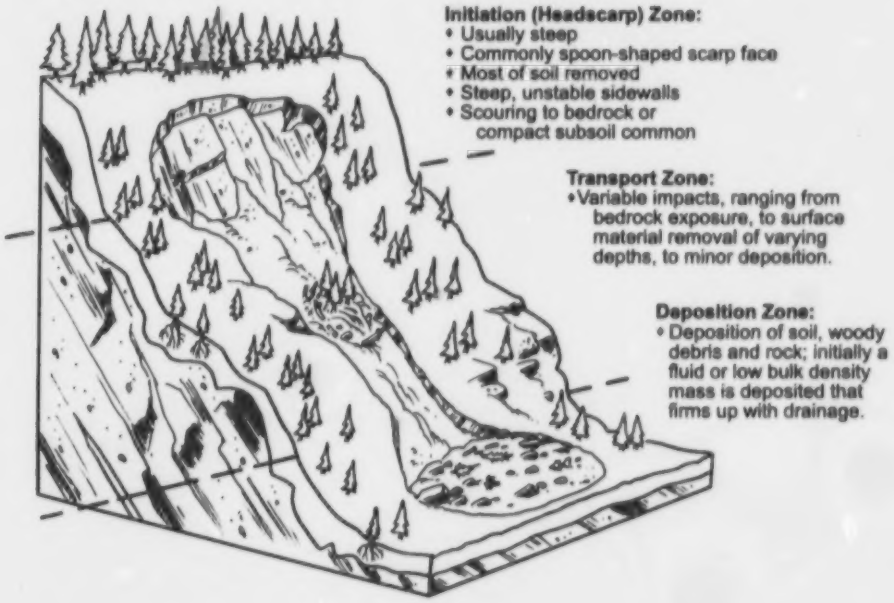

Initiation (Headscarp) Zone:
• Usually steep
• Commonly spoon-shaped scarp face
• Most of soil removed
• Steep, unstable sidewalls
• Scouring to bedrock or compact subsoil common
Transport Zone:
• Variable impacts, ranging from bedrock exposure, to surface material removal of varying depths, to minor deposition.
Deposition Zone:
• Deposition of soil, woody debris and rock; initially a fluid or low bulk density mass is deposited that firms up with drainage.

Fig. 4.03 Idealized landslide system

Secondary objectives of rehabilitation may be to mitigate visual impact, or to restore the site for wildlife or timber production.

In order to minimize offsite sediment delivery, a number of treatments may be required including:

- Stabilization of the headscarp or other oversteepened areas to reduce the potential for additional events. Actions to stabilize such areas may include resloping or recontouring, buttressing, or draining subsurface flow.

- Water management to mitigate excessive erosion. Treatment options include managing offsite water, controlling surface flow on the slide track within specific channels, and or constructing check dams or armouring erodible channels.
- Establishment of vegetation to provide erosion control, minimize mobilization and transport of sediment, and increase soil strength. This may include seeding, planting, soil bioengineering or the use of geotextiles in conjunction with vegetation. By minimizing further mass wasting and erosion, a more stable substrate is provided that will rehabilitate through natural succession by native species.

Rehabilitation of landslides or disturbed slopes is a process that may take many years to accomplish. Exposed surfaces are typically unstable and infertile with an absence of topsoil or vegetation. Consequently, follow-up inspections that provide for effectiveness evaluation and treatment maintenance are usually beneficial.

The three most important factors for successful long-term rehabilitation of landslides or disturbed slopes are:

- Initiating treatment **as soon as safely possible** after the event to reduce the amount of soil loss.
- Properly assessing headscarp stability and taking action to stabilize the headscarp if warranted (i.e., inherently unstable sites will be less amenable to revegetation efforts).
- Evaluating treatments for effectiveness and undertaking remedial work if required.

4.2 Assessment and Prescriptions

The assessment procedure for the rehabilitation of landslides or disturbed slopes is discussed in the course notes for the Landslide Rehabilitation Assessment Procedure (LRAP) short course (BCFCSN, February, 1997) and the subsequent Rehabilitation of Disturbed Slopes and Landslides short course (BCFCSN, August, 1997). The assessment procedure is designed for use by forest workers to record the basic physical and biological data necessary to develop preliminary treatment prescriptions. It is not intended to replace a thorough review by a qualified registered professional. If, however, a qualified registered professional is required to be responsible for the assessment or prescription, they should be included as early as possible in the process.

Field assessment involves mapping and measuring each site and segregating the site area into segments based on distinct physical and/or biological characteristics. Distinguishing characteristics may include slope gradient, substrate type, vegetative cover, hillslope landform (e.g. open slope or gully), aspect, nature of adjacent vegetation (e.g. mature timber or imature second growth), or a combination of any of these factors. The safety of personnel carrying out both the field assessments and the actual treatments is a primary consideration as most sites traverse locally steep to very steep terrain. This is especially critical for assessment of recent failures that may still be highly active. Assessment of the site for potential safety concerns should precede any field work on the landslide track. Personnel involved in this type of work should be cognizant of the hazards of working on steep slopes and take adequate safety precautions. In some cases, it may be prudent to conduct assessments remotely via helicopter or field glasses. For hillslopes where several failures occur in close proximity and are considered to have similar site characteristics, it may be justified to limit field assessments to a representative number of sites.

A field data card has been developed for the LRAP. There are, however, several methods currently in use within the different regions of the province for recording landslide data. Contacting local experts in the field will help to ensure that the most applicable method is used.

Critical field information to record includes:

- Requirement for geotechnical assessment. Professional assessment is recommended in cases where the headscarp area or other areas appear unstable with the potential for an additional failure large enough to be a safety concern, where the success of the work may be jeopardized, or where there is a high downslope consequence. Site indicators may include large-scale tension fractures along the edge of the headscarp or other evidence of potential instability upslope (e.g. pistol butt trees, thick poorly drained soils, extensive groundwater seepage, soil creep, pirated surface flow, oversteepened headscarp, etc). Figure 4.04 shows an oversteepened unstable landslide headscarp.

Fig. 4.04 *Landslide with unstable headscarp.*

- Landslide type and dimensions, suspected cause, characteristics of initiation zone and deposition zone.
- Age of the failure. This can be approximated from historical air photos or from the age of vegetation on-site. In general, more recent landslides should be given greater consideration for treatment as the erosion and removal of fertile soil material is less advanced.
- Connectivity to streams that may have fisheries values or water quality concerns. Connectivity to non-aquatic downslope resources (e.g. timber, infrastructure) may also be important. The degree of connectivity will influence the consequence and the priority for treatment.

By recording additional site information on the physical and biological attributes of each landslide segment, treatment requirements can be determined for each segment. Physical attributes include the length, width, path slope, path aspect, drainage, surficial materials, soil texture, coarse fraction, erosion pavement, average plantable depth, and plantable spots for each landslide segment. Biological attributes include total vegetation cover and vegetation cover by grasses, shrubs, hardwoods and conifers.

Fig. 4.05 Preliminary Treatment Prescriptions for Landslide Segments

Plantability	Substrate	% Vegetation Cover	Treatment
GOOD	A or B Soil (organic or mineral soil)	>50-65% *	Plant conifers.
		20 to 50-65%	Seed + fertilize, plant conifers.
		<20%	Fertilize/seed, plant conifers.
	C Horizon (parent material)	>50-65%	Interplant alders and conifers.
		30 to 50-65%	Fertilize/seed, interplant alder and conifers.
		<30%	Fertilize/seed, plant alder.**
MODERATE	B Soil	>50-65%	Interplant alders and conifers.
		20 to 50-65%	Fertilize/seed and interplant alders and conifers
		<20%	Fertilize/seed, interplant alders and conifers.
	C Horizon	>50-65%	Interplant alders and conifers.
		30 to 50-65%	Fertilize/seed, plant alder.
		<30%	Fertilize/seed and plant alder.
POOR	C Horizon	>50-65%	Plant alder.
		30 to 50-65%	Fertilize/seed, plant alder.
		<30%	Fertilize/seed.
	Rock	>50-65%	Leave as is unless pocket planting with alder to mitigate visual impact.
		30 to 50-65%	Plant alder or leave as is.
		<30%	Leave as is.

* 50% vegetation cover is considered to be a minimum for most Interior sites to address erosion, while due to generally higher rainfall factors, 65% vegetation cover is considered to be a minimum for most Coastal sites. For Interior sites where erodible soils are exposed, consideration should be given to increasing this minimum target vegetation cover.
** Planting of alder or conifers may not be required if natural seeding will occur readily.

Considerations that will affect any rehabilitation strategy include:

- **Age** If slide is recent, headscarp stabilization and immediate seeding should be high priority to minimize loss of productive soil.
- **Accessibility** Costs may increase if access for crews and equipment is limited. Aerial supported operations may be necessary.
- **Connectivity** Where impact to fisheries values or water quality is high, soil erosion should be mitigated as soon as possible to reduce sediment generation and transport. Where consequence is high, the use of specialized products (erosion control revegetation mats, bonded fibre matrix products) or techniques (soil bioengineering) may be justified despite increased costs. Connectivity to non-aquatic resources and human safety should also be considered.
- **Visual Concern** Consider planting and seeding with species that will provide better "green up" all year round.

- **Path Slope** Slopes greater than 50% generally require hydroseeding (truck or aerial). Steep slopes also influence safety considerations for workers onsite.
- **Site Drainage** Drier sites (e.g., south-facing, free-draining, low precipitation) require drought-tolerant species for seeding and planting; wetter sites favour planting of species such as willow, cottonwood and red osier dogwood.
- **Species Present** Naturally occurring species will be preferred for seeding and planting. Determine if local seed and/or cutting sources exist. For segments with mature timber adjacent it may be more cost-effective to allow natural regeneration to occur.
- **Timing** Late spring-summer seed applications may be subject to drought; late fall applications may be subject to frost. Early spring and early fall seeding are generally best but seed mix should be appropriate for expected site conditions. Dormant seeding on snow may be an option. Spring planting may be subject to heavier browse than fall planting.

Based on the site information and guided by Figure 4.05, appropriate preliminary treatment prescriptions can be developed. An agronomist, biologist or forester should review these preliminary prescriptions prior to development of final prescriptions. Final prescriptions should include treatment specifications such as tree species and spacing for planting, composition of seed mix and fertilizer and rates of application, timing of treatments, etc.

For any site, there may be a range of treatment options, each with an associated residual risk. At one end of this range of options, the decision to do no work may be warranted on sites where existing or potential risk is considered to be acceptable and there would be little, if any, cost-benefit from treatment. For sites where work is considered necessary to mitigate risk, residual risk typically decreases with an increase in treatment costs and/or with treatment options. Presenting a range of treatment options, their associated costs and expected levels of residual risk can facilitate the selection of an appropriate treatment. With this approach, a clear description should be provided as to the derivation of residual risk for each option.

4.3 Treatments

4.3.1 Headscarp Stabilization

Objective: To reduce the headscarp slope to a mechanically stable slope angle that will allow vegetation to re-establish. This stable angle will be dependent both upon the properties of the headscarp material (in situ compaction, texture, subsurface flow, etc) and the stability of the adjacent terrain. On sites with potentially unstable headscarp areas and high risk to downslope resources, inspection by a qualified registered professional is recommended in the development of an appropriate treatment prescription.

Description: Where landslides are several years old, the headscarps may have become mechanically stable over time. In these cases, the headscarps have ravelled, slumped or retrogressed back to a stable angle or to bedrock. For slope failures where the headscarps are still active, however, stabilization should be carried out if it is warranted by the risk to downslope resources or to proposed downslope treatments. Figure 4.06 shows resloping of a headscarp using an excavator. Where access for heavy equipment to carry out resloping is not practicable, alternative techniques may include:

- blasting of oversteepened headscarp material, while considering the stability of adjacent terrain, to reduce the slope angle;
- soil bioengineering to reduce the slope length by terracing with systems such as modified brush layers or wattle fences (see Section 6). **This technique is generally not appropriate where the potential failure plane is beyond the rooting depth of the plants**;

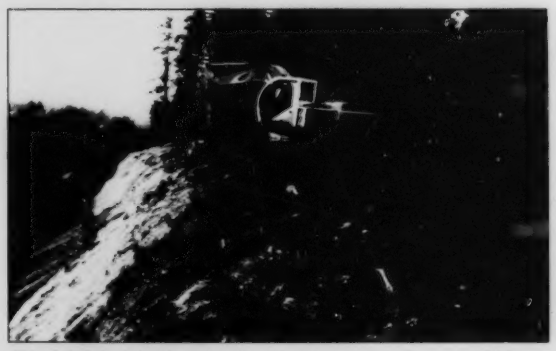


Fig. 4.06 *Mechanical resloping may be possible to aid in headscarp stabilization.*

- utilizing specialized machinery (e.g. Spyder hoe) for resloping;
- thinning or complete removal of trees above the headscarp in conjunction with any of the above treatments may be beneficial especially for sites prone to windthrow; and
- management of upslope water, including diversion of road drainage away from the headscarp to stable adjacent sites.

For road-related failures where headscarps occur at or adjacent to roads, stabilization can commonly be addressed through appropriate road deactivation that reslopes, removes or buttresses unstable material and manages road drainage effectively (see Section 3).

Prescription Indicators for Headscarp Stabilization:

- oversteepened slope
- tension fractures or ground surface displacement along the edge or upslope of the headscarp

- evidence of soil creep upslope (pistol butt trees, stepped or hummocky ground)
- thick soils with heavy groundwater seepage
- misdirected surface flow
- evidence of recent failures

Any action proposed to stabilize landslide headscarp areas should be practicable. The consequences of not stabilizing any headscarp must be carefully weighed against a potentially costly stabilization treatment.

Fig. 4.07 Spyder hoe resloping unstable cutslope.

Suggested Implementation Tips:

- **Worker safety will obviously be a major consideration** for any stabilization activities and applicable WCB regulations must be observed.
- Falling of large trees above the immediate headscarp should be considered prior to any resloping efforts if this can be accomplished safely. An experienced arborist may be able to recommend which trees to remove based on tree health and rooting depth.
- The use of specialized machinery to address sites with difficult access generally requires long-range planning to ensure equipment availability. Figure 4.07 shows a Spyder hoe resloping an unstable cutslope.
- Use of explosives to reslope headscarp areas has been attempted with limited success. If blasting is considered to be a viable treatment option, it may be better to proceed by blasting in small increments to attain the desired slope angle, rather than setting a few large charges with the intent of creating a stable slope. Overhanging root wads, for example, may be good areas to address with explosives. The advice of specialists is highly recommended.
- Soil bioengineering structures are generally not effective for deeper-seated headscarp instability but may be appropriate for downslope areas to reduce sediment transport. Soil bioengineering structures installed upslope of the headscarp area may provide a hydrologic benefit that can increase headscarp stability in some cases.
- For road fill failures, some fillslope pullback may be necessary at the headscarp to remove residual fills at risk; however, adjacent fillslope areas may warrant more extensive pullback to prevent similar failures.
- Control of surface runoff upslope of headscarp areas may provide a benefit to stability.

Cost Factors: Costs to carry out any of these treatments will be site specific depending mainly on site conditions and access.

Additional Comments:

- Risk assessment and management should probably be the main considerations when contemplating any type of headscarp stabilization. Actions to mitigate the consequences of additional failure of the headscarp may provide a greater cost-benefit in some cases (e.g. installation of downslope containment or deflection structures).
- Overall site stability may be improved by treatments at the toe of the landslide or along the landslide track. These might include buttressing with a toe berm or recontouring to create benches along the track. Efforts to manage subsurface flow through the installation of horizontal drains may be beneficial as well. It is recommended that any such actions be developed in consultation with a qualified registered professional.

4.3.2 Water Management

Objectives: To manage surface water on a landslide track or disturbed slope in order to reduce erosion and subsequent sediment transport. Unmanaged water may also be the underlying cause of instability on a site. Until sufficient vegetation cover is established, significant erosion by water can take place via sheet wash, rilling, gullying, and/or stream channeling. Erosion is most severe on sites underlain by easily eroded materials such as silts and fine sands. It is less severe on materials such as compact tills.

Description: Prescriptions for surface water control are governed largely by the existing hydrology on the failure surface or by the upslope drainage pattern. On older sites, stream channels and small gullies are typically well developed. In such cases, the intent should be to ensure that the water continues to flow in the established pathways, does not avulse and create new channels, or excessively erode existing channels. Appropriate treatments may include:

- armouring of the channels with rock (only cost-effective if suitable material is at hand);
- removing obstructions in the channels that could cause avulsion;
- constructing check dams or gully breaks to reduce flow velocities and channel erosion where practicable;
- restoring subsurface flow through the installation of soil bioengineering structures such as live pole drains (see Figure 4.08);
- using planting or soil bioengineering to stabilize channel banks and sidewalls; and
- upslope interception of surface or subsurface flow utilizing a ditch or interceptor drain.

Erosion by sheet wash is most easily mitigated by seeding to establish a grass and legume cover (see Section 4.3.3).

Prescription Indicators for Water Management:

- revegetation has been inhibited by water erosion
- there is potential for avulsion of channelized flow
- rills may be developing or starting to form gullies
- bank or channel erosion in established channels is severe

Fig. 4.08 Water management on recent landslide track includes installation of live pole drains and local armouring of channels.

Suggested Implementation Tips:

- In general, most actions to manage surface flow on a landslide track must be implemented mainly by hand. Worker safety on steep slopes is an important consideration and experienced crews are recommended.
- Diversion of water originating offsite may be possible as a means of reducing surface flows onto individual sites (e.g. through upslope road deactivation); however, it should only be considered if there is no increase in hazard on the adjacent hillslope.
- On-site materials (e.g. armour rock, willows) should be utilized for cost-effectiveness.
- For small channels/rills in compact, less erodible soils, flow velocities may be effectively reduced by continuous riprap, intermittent rock check dams (these should be keyed in on steep slopes), and live gully breaks. Live pole drains may be appropriate if anticipated flows are low enough.
- For rills and gullies in erodible soils, intermittent live gully breaks may be effective in reducing erosion. For low gradient channels, intermittent live silt fences may provide adequate sediment retention.
- Retrogression of small headscarp areas underlain by erodible soils may be treatable by construction of structures as shown in Figure 4.09. A combination of filter fabric and coarse rock are used to reduce erosive action.
- Any attempts to armour channels to mitigate either bank erosion or channel avulsion should consider the maximum flows anticipated and select rock size accordingly.

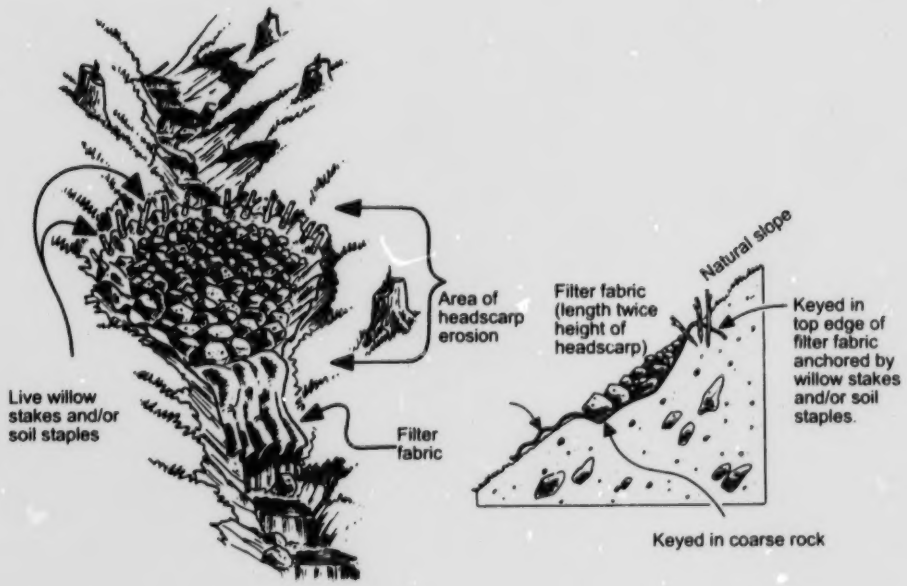

Area of headscarp erosion
Live willow stakes and/or soil staples
Filter fabric
Filter fabric (length twice height of headscarp)
Natural slope
Keyed in top edge of filter fabric anchored by willow stakes and/or soil staples.
Keyed in coarse rock

Fig. 4.09 Oblique view and longitudinal section of structure for treatment of gully erosion.

Cost Factors: For most of the above treatments, implementation by hand will be necessary and costs will, therefore, be site specific. General costs for construction of soil bioengineering structures are discussed in Section 6. Seeding costs will vary with method of application as discussed in Section 4.3.3.

Additional Comments:

- Management of surface water is best addressed as soon after the initial failure as possible. Seeding to establish a vegetation cover can play a significant role in reducing the initial effects of erosion by water and limiting the development of rills and channels.
- Any in-channel treatments to reduce erosion should ensure that the potential for channel avulsion is not increased.

4.3.3 Seeding

Objective: To control erosion by seeding a herbaceous cover. Seeding also contributes to the soil building process through the addition of organic matter and nutrients. For Coastal sites, a minimum vegetation cover of 65 % is recommended, while for most Interior sites a minimum vegetation cover of 50 % is recommended. Greater vegetation cover is required for Coastal sites due to higher rainfall factors. For Interior sites where erodible soils are exposed, however, consideration should be given to increasing the minimum vegetation cover to greater than 50 %. (see Figure 4.05)

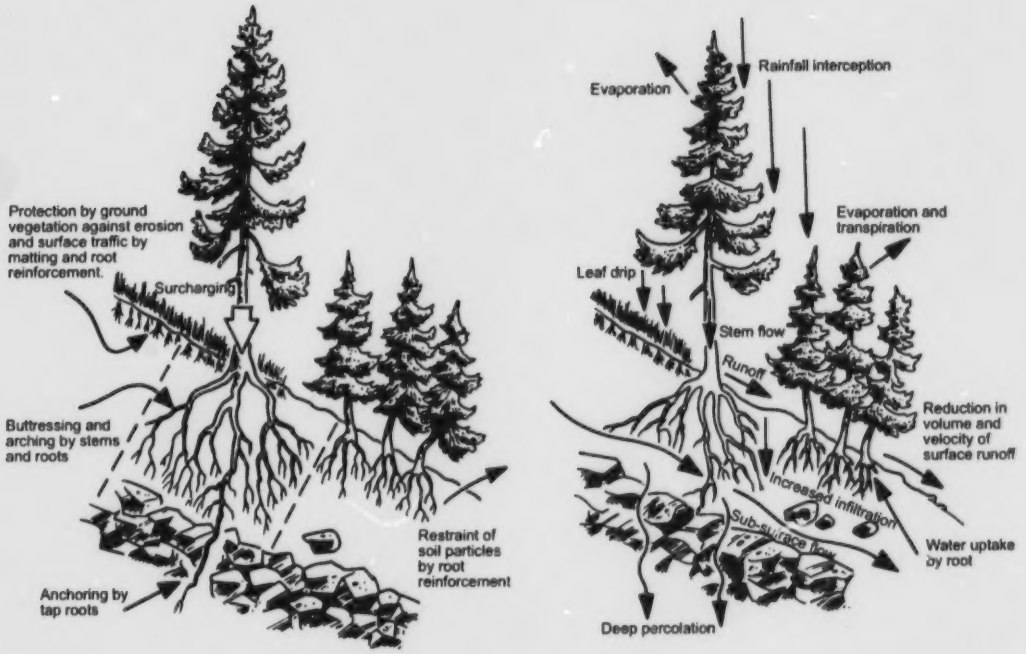


Fig. 4.10 Stabilizing effects of vegetation.

Description: Agronomic species of grasses and legumes are usually applied in combination with fertilizer to establish a vegetation cover that will provide protection from erosion by wind and rain. This is accomplished both by the mechanical effects (surface matting, root reinforcing) and hydrological effects (protection from rain impact, interception and transpiration, reduction of run-off velocities) of the established cover. Subsequently planted or naturally established woody species also contribute to these effects as well as providing deeper stability through anchoring, buttressing and arching effects. Figure 4.10 illustrates the stabilizing effects provided by vegetation. Seeded plants need reasonably warm temperatures as well as moisture to germinate and grow.

A seed mix of agronomic species is usually applied, rather than a single species of grass or legume, for the following reasons:

- to address short and long term erosion control. Some species establish and grow rapidly but are relatively short-lived, while other species establish and grow more slowly but are persistent;
- to withstand possible extremes of temperature and moisture during the initial period of germination and establishment. Drought-tolerant or frost-hardy species, for instance, may be included depending on potential weather conditions following application;

- to enhance nutrient levels in the soil. Nitrogen-fixing species such as legumes will create better growing conditions for accompanying seed species as well as for invading native species; and
- to meet management objectives.

There is significant interest in the use of native species in revegetation seed mixes for forest land restoration. At present, however, limited availability and higher cost for native seeds appropriate to BC forest sites make their use impractical. Although a commercial native seed industry is under development in BC, it has not yet been able to provide a viable option to the use of agronomic species.

The composition of the seed mixes used on forest land can have a profound effect on the vegetation that is established. All mixed seed is sold as a percentage by weight of each species so the actual number of seed of any individual species present is influenced by the relative size and density of the seed. A good discussion on the rationale for the composition of seed mixes and considerations for the balancing of seed mixes is provided in Polster (1999).

Species to be included in a seed mix should be selected to provide a diversity of rooting depths from shallow rooted species such as bluegrass to deeply rooted species such as alfalfa. A mix of bunch forming and sod forming species will provide the best coverage although care should be taken to avoid too many sod forming plants as these will inhibit invasion of the site by later successional species. Balancing seed mixes on the basis of seed weights will prevent the problems associated with having too much of the finer seeded species and not enough of the larger seeded plants. Any mix with more than 10 percent (by weight) total of redtop, bentgrasses or bluegrasses will result in domination by these species and should only be used under the direction of a specialist for a specific purpose. In most cases, seeded vegetation should be considered as a temporary initial cover for the disturbed site until the native species establish. Species that might prove to be too aggressive and too long lived, such as reed canary grass or crested wheat grass, should be avoided if possible. These species have the potential to severely disrupt ecological processes for many years if they become established.

Grass and legume seed mixes should not be applied at rates that exceed approximately 50 kg/ha. Over-application of seed may result in severe seedling competition to the eventual detriment of the established stand and planted or invading woody species.

Appropriate general seed mixes have been developed for most regions of the province. District Ministry of Forests staff can provide information on this subject. For seeding of areas with unique environmental conditions or with a need to meet specific objectives, a specialist may be able to provide valuable advice.

Seed mixes can be applied by dryseeding either by hand or aerially, or by hydroseeding either by ground-based equipment or aerially.

Dryseeding is generally accomplished using either a cyclone-type spreader, or a variety of spreaders or blowers that can be attached to vehicles, helicopter buckets or airplanes. Seed mix is applied at a rate of up to 50 kg/ha depending on the amount of existing vegetative cover.

Fertilizer is recommended for inclusion in most dryseeding applications. Unless there are indications to the contrary, a high analysis, balanced fertilizer containing all of the essential macro-nutrients, Nitrogen, Phosphorus and Potassium (N, P & K) applied at a rate of from 100 to 300 kg/ha will be suitable for most sites throughout the province. At these rates of application, there should be no detrimental effects to water quality or fish habitat. The practice of including products such as sulphur-coated urea to extend the period of nutrient release is generally not required for most fertilizer applications as the role of the fertilizer is to aid only in initial establishment. It is important to remember that the objective of most forest land revegetation programs is not to establish a dense and long-lived stand of grasses and legumes but to encourage the invasion of the site by native woody species. Application of fertilizer alone may provide a cost-benefit on sites where no seeding has been done previously and vegetation cover by native species is relatively well established (i.e. 30-50% cover).

Hydroseeding is the application of seed within a water slurry that commonly contains fertilizer, mulch, and tackifier. Specialized equipment is used to mix and homogenize the ingredients in large volumes prior to application. Application can be ground-based (e.g. pumped and sprayed from a truck-mounted unit) or dispersed aerially via helicopter bucket (see Figure 4.11) or from a fix-winged aircraft.

***Fig. 4.11** Heli-hydroseeding application.*

Hydroseeding can be very effective on landslides, gullies and other severe sites as the mulch and tackifier can help hold the seed in place and assist growth. Hydroseeding can also be effective in treatment of cutslopes and fillslopes on active roads.

Historically, application rates for seed have been 50-75 kg/ha, although a maximum rate of 50 kg/ha is considered by Polster (1999) to provide the greatest cost-benefit. Included within the slurry are 200-400 kg/ha of high analysis fertilizer and enough water to apply the resulting slurry evenly. Mulch usually consists of a specially prepared wood fibre material and is often added to hydroseeding mixes to enhance performance. However, care should be taken to avoid over-application of mulch (greater than 400 kg/ha) as this will only serve to slow growth and increase costs. The application rate for mulch is highly variable for ground-based operations. For aerial application, the mulch rate is generally less than 100 kg/ha to reduce weight. Applied at this rate, the mulch serves mainly to assist in homogenization and to act as a marker during application. Tackifier, which acts as a bonding agent upon application, is applied at various rates of up to 50 kg/ha. More concentrated varieties of tackifiers are available that require less product per hectare.

An acceptable hydroseed application has the following characteristics:

- Homogeneity. The mixing equipment and the density of the mixture must keep all ingredients in suspension until application. Homogeneity will ensure even distribution of individual products on the ground.
- Uniformity of application. The mixture should be applied as a uniform spray-like covering to produce an even distribution of the mixture and resulting vegetation.
- Accuracy. The mixture should be applied over the intended target area with minimal overspray or wastage.

Prescription Indicators for Seeding: See Figure 4.05 for general recommendations on seeding applications.

Suggested Implementation Tips:

- When planning for seeding programs, consultation with a seed specialist (e.g. agronomist) may be justified if site conditions are atypical or if there are specific performance requirements. Species selection for a seed mix should be weighted toward seed characteristics with less emphasis on seed costs.
- In coastal areas at low elevations, seeding should be conducted from mid-March to mid-April, or from mid-August to mid-September. At higher elevations on the Coast, the spring seeding period can be extended into early May while the fall seeding should be limited to the last two weeks in August and the first week of September. For damp northern coastal areas such as the Queen Charlotte Islands, experience has shown that the seeding window can extend continuously from mid-March to mid-September.
- The diversity of edaphic and climatic conditions in Interior locations makes selection of the best seeding times more difficult. However, as a general rule, seeding in the Interior and northern locations can be conducted about three weeks after the snow leaves the site, but generally not after the end of May. Late summer seeding during the last two weeks of August is often very effective for Interior sites, particularly those at higher elevations. Late fall seeding, just before the first winter snowfall is another good time to seed in the Interior. In some cases, however, when seeding is conducted too early, legumes may germinate and then be killed by frost. Seeding can also be conducted on top of early winter snow. In all cases, consideration should be given to seeding at a time when either the seed will have a chance to germinate and grow immediately or will remain dormant until favourable conditions prevail. Significant seeding losses can occur when seed is applied just before extended dry weather periods and the young seedlings have not developed sufficiently to withstand the drought. Checking with the long term climatic records (Environment Canada, 1993) for the treatment site area can assist in selecting the best time for seeding.
- For most dryseeding applications, fertilizer is usually applied on a separate pass. Mixing seed and fertilizer together will aid in distribution of the lighter weight seed. Some success has been shown in trials using seed prepared with a nutrient/fertilizer coating. Use of this product requires only a single pass application.

- Dryseeding directly by hand without a spreader device should be discouraged as it typically results in a non-uniform distribution of seed (i.e. produces patches of vegetation rather than a uniform cover).
- Dryseeding works best on slopes with gradients generally less than 50%; however, application on steeper slopes may be effective if the slope is rough and loose or has significant existing vegetation cover (30%). On certain sites with slope gradients less than 50%, however, hydroseeding may be the preferred seeding technique for sites with compact uniform substrate or for sites exposed to wind.
- Hydroseed application can be easily monitored if the treatment area has been accurately measured as it is relatively simple to calculate the volume of mixture required for treatment of a given area. Where treatment areas have not been accurately measured, monitoring via the use of randomly placed sample cards may be an option. (see Figures 4.12 and 4.13).
- For sites or segments where soil conditions are considered to be marginal (e.g. rocky sites with only local pockets of soil), dryseeding or hydroseeding at a lesser application rate may provide the greatest cost-benefit.
- For operations in remote locations that require high mobilization costs, projects should be amalgamated if practical to achieve the greatest cost-effectiveness through economy of scale. Unit rates for treatments such as aerial hydroseeding can be reduced substantially in this manner.
- When planning for aerial treatments such as heli-hydroseeding, local "weather windows" should be utilized to minimize down time provided these windows coincide with favourable periods for plant establishment.
- For aerial applications it is often beneficial for the site supervisor to preview the sites with the pilot to ensure that seeding coverage is optimized.
- For sites with large uniform areas requiring aerial seeding, it may be more cost-effective to utilize the largest capacity aircraft possible to minimize cycle times. For projects with numerous sites requiring 'spot' treatments, smaller aircraft may provide for a more cost-effective application.

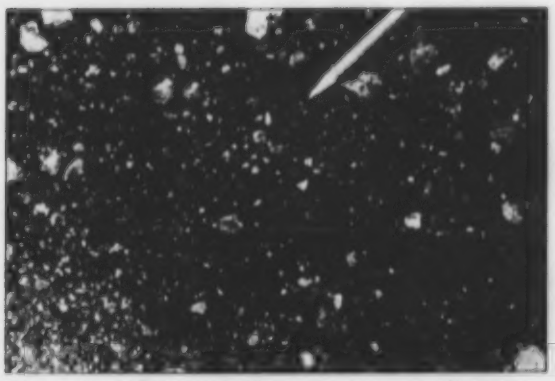


Fig. 4.12 *Uniform and homogeneous application of hydroseed slurry on ground*

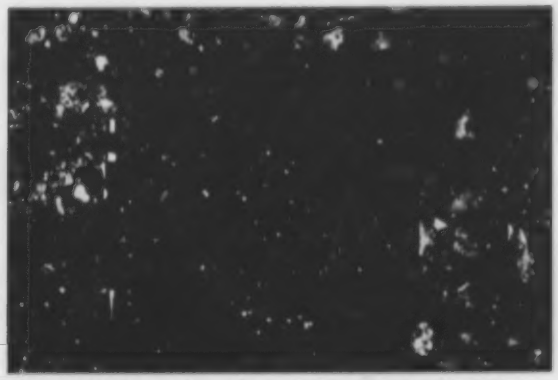


Fig. 4.13 *Use of cards to aid in monitoring of hydroseed application.*

Cost Factors: Costs for seeding will be dependent on the application method, application rate, product specifications, prevailing product prices, access and size of the project. General historical ranges during the 1990's are as follows:

- dryseeding by handseeder: $200-$400/ha for seed and fertilizer; labour not included but may exceed product costs/ha
- dryseeding with equipment: $200-$400/ha for seed and fertilizer; equipment costs not included
- ground-based hydroseeding: $1,500-$5,000/ha depending mainly on mulch rate
- aerial hydroseeding: $1,500-$3,500/ha depending on flight logistics and scale of operation (aircraft cycle times will largely determine cost-effectiveness)

Additional Comments:

Regardless of the application method chosen, seeding should be considered as a priority for most recent landslide events unless the timing would not be conducive for germination and establishment. Where there is a need for immediate erosion control, seeding can be used in conjunction with specialty products to increase the treatment effectiveness. This may include:

- dryseeding through erosion control revegetation mats;
- hydroseeding with higher mulch contents; and
- seeding with bonded fibre matrix products.

4.3.4 Planting

Objectives: To provide deeper soil stability by planting shrubs and/or trees on landslides or disturbed sites. Planting will accelerate soil development, provide habitat for wildlife, mitigate visual impact and restock for timber.

Description: Most disturbed forest sites in British Columbia will benefit from the initial establishment of pioneering species, although where natural forest soil horizons have remained in place, this pioneering stage woody species growth may be eliminated. Pioneering species such as alder (*Alnus rubra, A. crispa* and *A. tenuifolia*) are recognized in British Columbia as distinct taxa by Brayshaw (1996). Alder is important on most disturbed sites as it associates with nitrogen fixing bacteria (*Frankia*) and can provide substantial amounts of nitrogen for subsequent forest growth. Other pioneering species such as soopolallie (*Shepherdia canadensis*) are also associated with nitrogen fixation and are important in the vast fire-dominated lodgepole pine stands of northern British Columbia. In addition to nitrogen fixation and soil improvement, pioneering species create the conditions that allow soil micro-organisms (fungi, bacteria, viruses) to establish and thus create conditions where later successional species can thrive. Consideration should, therefore, be given to using pioneering species in the revegetation of a majority of disturbed forest sites.

Pioneering woody species can be planted as container grown seedlings or can be established from seed. Normal tree planting techniques are used when planting pioneering woody species, although care should be taken to avoid fertilizing alder plantings as this will inhibit natural nitrogen fixation. Seeding in alder has been shown to be an effective means of establishing these species. Alder seed weights range from 1,480,000 seeds/kg for red and mountain alder to 2,800,000 seeds/kg for sitka and green alder (Young and Young, 1992). With normal seed losses and germination percentages, less than 0.1 kg/ha of alder seed is needed to establish a healthy stand. Alder seed can be purchased from a variety of woody plant seed suppliers.

Planting of shrubs that have a natural ability to survive on infertile sites, such as willow, red osier dogwood, twinberry and salmonberry, will enhance soil development by providing humus. They will also provide some measure of erosion control and soil stability as well as enhancing wildlife habitat and reducing visual impact.

Fig. 4.14 Planted conifers on unseeded landslide track.

Prescription Indicators for Planting:

- mechanically stable areas lacking in vegetation cover
- relatively infertile areas that could benefit by planting with nitrogen-fixing species
- sites sufficiently fertile to support conifer growth (see Figure 4.14)
- areas where immediate natural regeneration is unlikely

Suggested Implementation Tips:

- Coordinating landslide planting with restocking activities will increase cost-effectiveness.
- If planting prescriptions are to be implemented, one must ensure that sufficient and appropriate stock is available. This may require advance planning of up to 12 months or more. Experience has shown that what is often planted is stock at hand, regardless of species. This can result in the planting of species that are less than optimal for the site.
- Planting is best conducted when the plants are dormant, although in some cases where there is abundant moisture and conditions are not too harsh, such as on northern exposures, planting can be successfully conducted later into the summer. Fall planting, as the vegetation is approaching dormancy and the ground is moist from the fall rains, can be a favourable time to plant restoration species. Planting at this time may also alleviate heavy browsing by ungulates in certain areas. Care should be taken to avoid times when the newly planted vegetation will be exposed to extended dry periods.
- For small remote areas, it may be more practicable to allow these areas to restock naturally.

Cost Factors: Planting costs are generally comparable to operational planting costs. Higher costs may arise if equipment, such as ropes and harnesses, are needed to complete the work safely.

Additional Comments: On less fertile sites that are treated by seeding and planting with species such as alder, it may be several years before conifer planting should be considered. Conifer planting on landslides for the purpose of commercial harvest is generally not appropriate on the upslope portions of most landslide tracks due to site infertility and inherent slope instability. Planting of conifers is, however, often appropriate on the deposition zones of landslides, particularly the fans, as these areas are commonly extremely productive sites. Planting on fan zones can also provide stability to existing channels. Planting of any tree species that are prone to windthrow should be avoided on the upslope portions of sites as they may contribute to future instability. Where heavy browsing by wildlife is a concern, it may be better to delay planting until fall when alternate food sources are readily available. Final specifications for species, planting densities and time of planting, however, should be carried out by a forester, agronomist, or biologist based on site conditions, management objectives and performance. Where appropriate, a qualified registered professional forester should review rehabilitation plans.

A Silviculture Prescription may be required for any restocking that utilizes commercial species.

4.3.5 Soil Bioengineering

A number of soil bioengineering structures may be suitable for the rehabilitation of landslides and disturbed slopes where ravelling or surface instability are concerns that may limit revegetation. Refer to Section 6 for details.

4.3.6 Specialized Techniques

Specialized techniques that may be applicable to the rehabilitation of landslides and disturbed slopes include the use of man-made products such as erosion control revegetation mats, specialized compounds such as bonded fibre matrix products for seed application, and a variety of concrete block products. These products are generally not cost-effective for use on a large forest site but may be justified where access is good and the risk to downslope resources is very high. A discussion of these techniques is beyond the scope of this document and consultation with an erosion control specialist is recommended.

4.4 Regional Factors

Although the landslide rehabilitation assessment procedure is applicable throughout all regions of the province, rehabilitation objectives and treatments will be influenced by regional variations in geomorphology, climate, and concerns for wildlife habitat and land use. Regional variation will be most notable on detailed revegetation specifications as species selection will be targeted for each biogeoclimatic zone or sub-zone.

4.5 Other Considerations

The rehabilitation of landslides and disturbed slopes typically requires a team approach with personnel familiar with terrain stability, surface hydrology, erosion control, revegetation and forestry. Experienced technicians may carry out the initial field assessments but qualified personnel are recommended where site stability is of concern, where worker safety may be at risk, where immediate erosion control is required to protect important downslope resources, or for the development of revegetation specifications.

For large project areas with numerous sites, an initial aerial reconnaissance is recommended to verify the interpretations of any overview assessments. As these assessments may have been conducted one or more years prior to the field assessment, there may be additional failures or reactivation of inventoried failures that could affect the overall treatment priorities. As well, natural revegetation or erosion may have sufficiently altered site conditions. From this reconnaissance it may also be possible to limit the number of sites that require detailed field assessment (i.e. select the optimal number of representative sites) or identify sites where rehabilitation is no longer practicable.

Prior to field assessment it is useful to complete a general plan of individual sites from the aerial photography or from detailed maps. This allows for easy plotting of field observations such as areas where bedrock is exposed, areas adequately revegetated, zones of recent failure and surface dimensions.

Field assessments should be conducted during safe working conditions but also during a period when vegetative cover is most easily observed and estimated. Actual field traverses on large sites are most efficiently carried out using both a hip chain to measure slope distances and a rangefinder device to record treatment widths. Coloured spray paint can also be used to delineate areas for treatment or non-treatment (e.g. for aerial hydroseeding).

Preliminary prescriptions for individual sites within the project area should be compiled and reviewed with respect to logistics. For example, where remote sites are prescribed predominantly for aerial hydroseeding, it may be more practical to hydroseed all treatment sites in the area, even though some may only require dry seeding.

Where landslide tracks have been scoured to infertile parent material, it may be possible to improve fertility by importing 'topsoil' from adjacent areas. This type of site preparation is often possible for road fillslope failures where unstable organic-rich fill on either side of the failure can often be retrieved and cast onto the slide surface. For this type of treatment, revegetation must be done immediately after placement of the material to reduce loss of the introduced soil. Temporary sediment control measures may also need to be taken until revegetation is sufficiently established. This treatment should only be considered where the slope gradient is not extreme (<60%), where the slope is naturally benched, and where expected surface flow is low (i.e., no significant channels occur) and potential sedimentation can be adequately controlled.

5.0 Gully Rehabilitation

5.1 Introduction

Gully systems represent sites of active erosion and deposition associated with steep slopes. The upslope portions of gully systems may have significant potential to generate mass wasting events such as channelized debris flows and debris floods, while the lower portions may be subject to channel avulsion. For coastal B.C., the management and rehabilitation of gullies is guided by the FPC's Gully Assessment Procedure Guidebook. Although this procedure was developed for use on the Coast, many aspects of it may be applicable to Interior sites.

Gully rehabilitation is generally recommended where:

- there is a high likelihood for initiation of a channelized debris flow or debris flood with high downslope consequences;
- there are unnaturally large volumes of woody debris in recently logged gullies that could be incorporated into either a channelized debris flow or debris flood with high downslope consequences; and
- there is high risk of erosion and sediment transport from a gully.

The intent of this section is to:

- provide a brief review of gully geomorphology;
- summarize the Gully Assessment Procedure and discuss which aspects may be applicable to Interior sites;
- discuss how the site information is utilized to develop an appropriate treatment prescription;
- describe and illustrate possible treatment types;
- provide practical advice for prescription development and implementation; and
- discuss factors that affect treatments and treatment costs.

An idealized gully system is shown in Figure 5.01. The headwall zone is the steepest and, generally, least stable portion of the gully system with slope gradients generally in excess of 50%. The transport zone is generally defined by a perennial or intermittent stream confined by steep, typically unstable gully sidewalls. Wedges of temporarily stored sediment and/or woody debris may occur. Channel gradients range from approximately 25% to 50%. The fan zone marks the deposition zone for sediment and debris transported from upslope. Fans may include single or multiple channels ranging from deeply incised to fully unconfined. Slope gradients are generally less than 25%.

The two primary hazards of concern in gullies are channelized debris flows and debris floods. A channelized debris flow may be triggered by a small landslide from the steep sidewalls or headwall of a gully, or by landslides entering gullies from adjacent slopes. Large amounts of both sediment and woody debris are entrained and transported as a coherent flowing mass as the debris flow descends the gully channel. Because of their large volume, speed and depth of flow they are the most destructive events associated with gullies. Debris floods occur during the transport of debris down gullies by large volumes of water. As water is the main constituent, debris floods do not behave as coherent flows and are, therefore, less destructive events. The initiation of either a channelized debris flow or debris flood depends on critical combinations of gully features

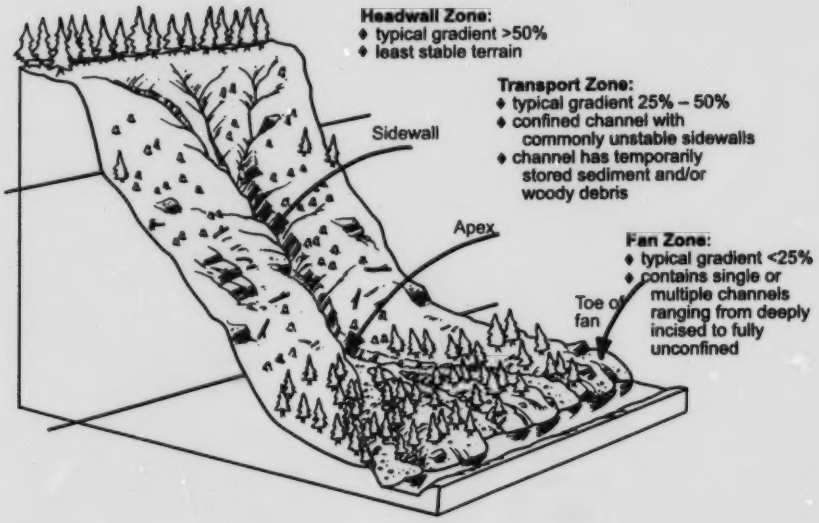

Headwall Zone:
♦ typical gradient >50%
♦ least stable terrain
Transport Zone:
♦ typical gradient 25% – 50%
♦ confined channel with commonly unstable sidewalls
♦ channel has temporarily stored sediment and/or woody debris
Sidewall
Apex
Fan Zone:
♦ typical gradient <25%
♦ contains single or multiple channels ranging from deeply incised to fully unconfined
Toe of fan

Fig. 5.01 Idealized gully system

including the slope of the gully catchment area, the availability of loose entrainable material, the stream channel gradient and the drainage basin area. Harvesting-related factors include the amount of soil disturbance on the gully headwall and sidewalls during yarding, the volume of debris left in the gully, destabilization of sidewalls and headwalls by the removal of trees and the occurrence of unstable road crossings and/or poor road drainage control.

Coastal gullies are defined by system dimensions. The GAP Guidebook defines a gully system as having a channel with an average stream gradient of >25 % from the fan apex to the top of the headwall, with at least one stream reach that is greater than 100 m long with sidewall slopes ≥40 %, an average channel gradient of ≥20 %, and sidewall slopes ≥3 m in length.

Gully features occurring in the Interior were formed by similar geomorphic processes but generally have a lower frequency of debris flow and debris flood events. This difference may be related to differences in precipitation (i.e. a higher proportion of precipitation in the form of snow versus rain) and/or less intense logging of upper slope gully headwall areas in the Interior. Gullies in the Interior with intermittent or ephemeral streams (i.e. 'gulches') underlain by erodible materials, such as lacustrine and glaciolacustrine sediments, may have developed over a geologically short timeframe. A common hazard associated with this type of gully feature is the development of mud or debris slides during flash flood events. Snow avalanches and rain-on-snow flood events may constitute additional hazards associated with gully features in the Interior.

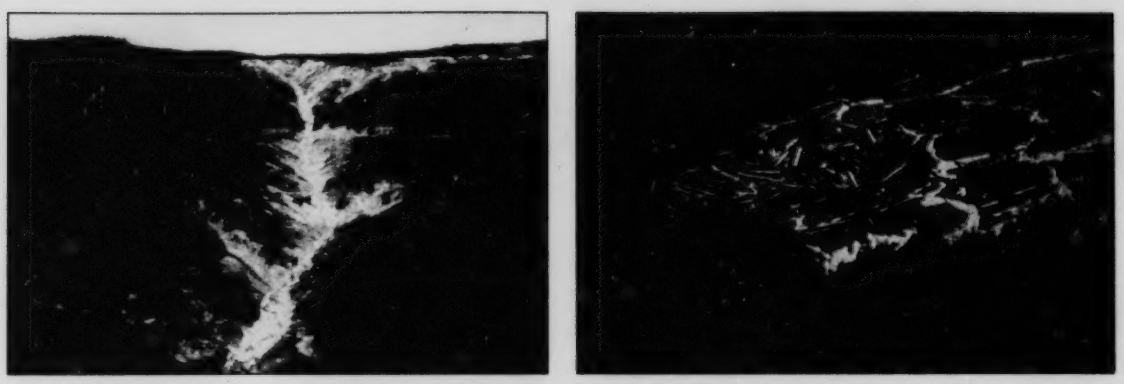


Fig. 5.02 Significant hazards associated with gullies include channelized debris flows and debris floods. A large gully scoured by repeated channelized debris flows (left). Deposition from debris flood event (right).

The objectives of gully rehabilitation can include:

- Reducing the potential for channelized debris flows or debris floods. This may be accomplished by taking measures to stabilize the adjacent hillslope, by removing road fill material from gully channels and/or by making gully crossings failsafe;
- Reducing the volume of potential channelized debris flows or debris floods. Reduction of unnaturally high levels of woody debris in the channel may be accomplished by gully cleaning;
- Restoring sediment delivery to natural levels. Erosion and sediment transport may be reduced through selective cleaning of woody debris, by management of surface water and through revegetation treatments;
- Mitigating the impact of channelized debris flows or debris floods when rehabilitation is not practicable. Construction of structures to deflect or contain such events may be possible to mitigate effects to downstream resources; and
- Protecting roads that may cross gully transport or deposition zones.

The GAP assessment can provide valuable information for post-harvest rehabilitation, whether for operational purposes or for watershed restoration. Parts of the GAP may be applicable to gully features in the Interior and aid in determination of gully hazards and rehabilitation options. Interior gully features that may benefit from a GAP include those that are erosionally active, those where stability conditions have changed as a result of upslope forest development (e.g. changes to hillslope hydrology), or those where upper slope road crossings pose a high debris flow potential.

5.2 Assessment and Prescriptions

The GAP is designed to determine the potential for the initiation of debris flows and debris floods in upslope reaches of the gully, or the potential for channel avulsion on the fan zone through the observation and/or measurement of key gully attributes. This assessment procedure is well documented in the GAP Guidebook. A revised version of this guidebook is being developed for publication in 2001, however, only minor changes to the assessment procedure are anticipated. Additional information on the factors that govern debris flow initiation in coastal settings is provided in Forest Research Technical Report TR-002: Debris Flow Initiation in Coastal British Columbia Gullies (Millard, 1999).

Both management and rehabilitation strategies for gully systems are dependent on factors that include:

- upslope debris flow potential - the likelihood of a channelized debris flow initiating upstream of the reach being assessed;
- water transport potential - the capacity of the stream flow to transport sediment and woody debris;
- debris flow initiation potential - the likelihood of a channelized debris flow initiating within the reach being assessed; and
- fan destabilization potential - the likelihood of channel avulsion on the gully fan.

For gully reaches that have been affected by channelized debris flows or debris floods, a landslide rehabilitation assessment (see Section 4.2) should be carried out in conjunction with the gully assessment procedure to aid in prescription development.

Trained field staff can carry out the gully assessment procedure, however, where substantial hazard or high downstream resource values or safety concerns are identified consultation with a qualified registered professional is recommended.

Field assessment involves traversing the gully channel and determining the upslope potential for initiation of debris flows, the water transport potential, and the debris flow initiation potential for each gully reach. For assessment of gully fan zones, a determination of the fan destabilization potential for each fan reach is also required.

Gullies typically comprise steep and wet terrain that may compromise the safety of personnel carrying out the field assessments. As well, there may be potential for sidewall or headwall failures, channelized debris flows or debris floods and snow avalanches. Fieldwork in gully channels should not be carried out during or immediately following high-intensity or long-duration rainstorms or rain-on-snow events.

Evidence of past channelized debris flows (e.g. scoured transport zone, deposition of a fan or hummocky debris lobes at slope breaks) provides an indication of a high upslope debris flow potential. This may influence post-logging rehabilitation strategies for downstream reaches. For example, in reaches where large volumes of logging debris occur, gully cleaning might be appropriate to reduce the amount of debris likely to become entrained in any channelized debris flow that passes through that reach. In other cases, construction of mitigation structures may be appropriate to reduce the impact to downstream resources if it is not practicable to reduce the upslope hazard.

An assessment of the water transport potential within a specific gully reach may be used to determine the likelihood of mobilization of debris and sediment during peak flow events. Action to reduce the potential for debris floods or the transport of logging debris into fish-bearing stream reaches may be beneficial. Treatment options may include cleaning debris from the channel and deactivating or flood-proofing road crossings. The water transport potential is based mainly on measurements or observations of actual physical processes. Therefore, its determination should be equally valid for either Coastal or Interior gullies although some calibration may be required for Interior applications.

The determination of debris flow initiation potential within a specific gully reach may indicate if removal of logging debris from the gully channel is necessary. Cleaning may be warranted to reduce the volume of a potential debris flow where large amounts of logging debris occur.

Assessment of fan destabilization potential is restricted to the fan zone of the gully system and provides an indication of the likelihood of channel avulsion. As channel avulsion can result in severe erosion and unacceptable downstream impacts, rehabilitation efforts should consider measures that will lead to increased stability on the existing active channels. Treatments that may be appropriate for fans with a high fan destabilization potential include:

- excavating excessive sediment and debris accumulations to enhance or restore channel incision;
- planting fast-growing hardwoods along the channel margins; and
- cabling log structures to existing stumps or other stable debris outside the channel.

Construction of deflection berms or catchment basins on fan zones to mitigate the consequence of future channelized debris flows or debris floods may be appropriate in some situations (Figure 5.07).

The amount of logging debris in a gully system may greatly influence the rates of erosion and sediment transport and, as a result, channel stability. Over time, however, there is generally decreasing cost benefit to cleaning logging debris from gullies. For gullies where it has been more than two years since the logging took place, it is often not useful to clean logging debris. Cleaning of woody debris, however, may be warranted to meet specific rehabilitation objectives depending on the water transport potential, the upslope debris flow potential, the debris flow initiation potential and the volume of woody debris present. The following section on gully cleaning is taken largely from the Gully Assessment Procedure Guidebook - Draft (04/04/00).

Gullies with high or moderate water transport potential will transport woody debris and sediment, resulting in increased scour of sidewalls, storage of sediment and woody debris in jams, and often greater amounts of sediment and woody debris delivered to downstream channels. If a logged gully containing large amounts of logging debris experiences a debris flow, the result will be a larger debris flow and greater damage. In cases where logging debris has resided in a gully for several years, the wood often becomes partially buried in sediment and incorporated into the channel structure. Removal of buried woody debris generally results in more harm than good, therefore, it is important to remove logging debris shortly after its introduction to the channel.

The decision as to whether logging debris should be removed depends on the hazards within the gully, the downslope/downstream resources, the amount of logging debris in the channel, and the relative amounts of sediment stored behind the debris. The following objectives are used to assess whether to clean logging debris from gully channels. Each cleaning objective should be evaluated separately, but the appropriate cleaning method may need to achieve more than one objective.

- **Cleaning Objective for Water Transport Potential:** Remove all logging debris that can be transported by peak flows. The size of logging debris pieces removed should increase as channel size increases. Pieces of natural woody debris that are broken up into small pieces during falling and yarding operations should also be removed.
- **Cleaning Objective for Debris Flow Initiation or Upslope Debris Flow Potential:** Remove almost all logging debris to reduce total volume of woody debris which could be incorporated into a debris flow.

- **Cleaning Objective for Fans:** Remove almost all logging debris to prevent a channel avulsion (change in channel location). Channel avulsions that are affected by the presence of logging debris are primarily a result of water transport. The deposition of debris flows is unlikely to be significantly affected by logging debris within a fan channel.

The table in Figure 5.03 provides post-logging cleaning strategies for gully and fan channels. Water transport potential will be the main consideration for any cleaning of channels. Other considerations include potential debris flow volumes for headwall and transport zones, and potential channel avulsion on fan zones. When deciding whether to clean channels several years after logging, consider the cleaning principles listed in this table.

Fig. 5.03 *Post-Logging Management Strategies for Removing Logging Debris from Gully and Fan Channels (from Gully Assessment Procedure Guidebook - Draft 04/04/00).*

Cleaning Strategies for Water Transport Potential		
Downstream Impact Potential	**Water Transport Potential**	**Action**
High or Mod	High or Mod	Clean all logging debris likely to move during peak flow events if the debris load is moderate or greater.
Low	High	Clean all logging debris likely to move during peak flow events if the debris load is moderate or greater.
High or Mod	Low	Do not clean
L	Mod or Low	Do not clean

Cleaning Strategies for Debris Flows		
Downstream Impact Potential	**Upslope Debris Flow Potential *or* Debris Flow Initiation Potential**	**Action**
High or Mod	High	Clean almost all logging debris if the debris load is heavy or very heavy
High	Mod	Clean almost all logging debris if load is very heavy
High	Low	Do not clean
Mod	Mod	Clean almost all logging debris if the debris load is very heavy
Mod	Low	Do not clean
Low	High, Mod, Low	Do not clean

The amount of woody debris covering the channel is assessed visually. Possible choices are:

Sparse	<20% of the channel is covered by scattered woody logging debris
Moderate	20 % to 80 % of the channel is covered by scattered woody logging debris, or there are two or three accumulations ≥1 m deep and ≥10 m long
Heavy	>80 % of the channel is covered by woody logging debris, or there are four or more accumulations ≥1 m deep and ≥10 m long
Very Heavy	>80 % of the channel is filled with woody logging debris ≥1 m deep

Cleaning Strategies for Channels on Fans			
Downstream Impact Potential	**Water Transport Potential**	**Fan Destabilization Potential**	**Action**
	High or Mod	High or Mod	Clean all logging debris if the debris load is moderate or greater
High or Mod	High or Mod	Low	Follow Water Transport Potential cleaning recommendations
	Low	High, Mod, Low	Do not clean
	High	High	Clean all logging debris if the debris load is moderate or greater
Low	Mod	Mod	Clean all logging debris if logging debris load is heavy or greater
	Mod	Mod	Do not clean if logging debris is less than heavy
	Low	Low	Do not clean

Several basic principles usually apply when cleaning woody debris. These include:

- Do not remove or cut natural large woody debris. Removing natural woody debris may destabilize channel banks and may result in significant amounts of sediment and woody debris being transported downstream;
- Do not remove logging debris that does not affect the potential for debris build-up or debris flows in the channel;
- Do not remove logging debris that is potentially unsafe to move;
- For channels where it has been more than two years since logging, it is often not useful to clean logging debris. Generally, do not remove logging debris that is buried in sediment. Remove woody debris that is mobile and will be transported downstream;
- Remove logging debris that is trapping sediment and additional woody debris. This may necessitate cutting pieces of wood to leave the portion of the log that is buried in sediment, while removing the portion that will trap more debris and sediment;
- If a channel shows no sign of logging debris movement several years after logging, it may not be beneficial to remove the debris, except to reduce potential debris flow volume;
- Always leave some large woody debris in the channel. Such debris should be $\geq$0.5 m in diameter and $\geq$3 channel-widths in length;
- Place all removed woody debris well beyond the limits of peak water flow and on stable ground. If woody debris cleaning is done to reduce potential debris flow volume, place all woody debris outside of the gully; and
- Do not burn slash accumulations within the channel.

If sediment loads are moderate, heavy or very heavy, and if removing the woody debris causes a rapid release of sediment with significant downslope/downstream consequences, it may be prudent to leave the channel untouched. In this case options may include the excavation and removal of excessive sediment, or the construction of sedimentation basins or debris flow control structures.

Woody debris jams may result from either debris flows or high water flows. Normally, removal of woody debris from jams should only be considered when the wood is not yet storing sediment. Recent debris flow jams that appear to be unstable may need to be removed. Consult with a qualified registered professional before removing woody debris jams.

In cases where there are high downstream resource values, or the risk is high, a qualified registered professional should be consulted.

A range of treatment options may exist including leaving the site as is when residual risk is considered to be acceptable. Presenting a range of treatment options, their associated costs and expected levels of residual risk can facilitate the selection of an appropriate treatment. A clear description is required as to the derivation of the residual risk resulting from each treatment.

5.3 Treatments

5.3.1 Gully Cleaning

Objectives: To reduce the impact of logging debris on debris flow or water transport volume, or on channel avulsion. Cleaning woody debris from gully channels is generally a labour-intensive and costly process and should only be carried out where the long-term benefits are clear. If in doubt, consultation with a qualified registered professional is recommended. Cleaning logging debris from gullies to reduce the risk of sidewall erosion may also be an objective but should also be carefully reviewed as studies by Rollerson, (1999) and Millard (2000) indicate that retention of logging slash may in some small streams limit or prevent damage to the stream channel.

Description: Cleaning may be carried out solely by hand or in conjunction with helicopters, or by utilizing large (e.g. swing yarders) and small (e.g. chain saw winches) cable systems. For discrete debris jams bounded by competent sidewalls it may be possible to utilize explosives to loosen or spread the woody debris. In any case it is critical that all removed woody debris be placed in a stable location above the high water mark of the channel. Care should be taken to leave any large woody debris that is natural in origin or is embedded within the channel.

Prescription Indicators: Gully cleaning may be warranted based on the results of a gully assessment procedure and/or from review of Figure 5.03.

Suggested Implementation Tips:

- For safety considerations, any cleaning of gully channels should be carried out during dry conditions when debris flow and avalanche hazards are low.
- Only experienced crews should be employed when large woody debris must be removed with machinery or helicopters. Crews should have implicit instructions on what should and should not be removed and where it should be moved to.
- Helicopter-borne slings and grapples have been used successfully (Figure 5.04). Effective ground-to-pilot communication is essential.
- Debris cleaning is most easily accomplished at road crossings during road deactivation and may provide the greatest benefit in terms of hazard reduction.

Cost Factors: Costs will be site specific. Gully cleaning using a helicopter on Vancouver Island averaged approximately $10/lin m of gully channel in 1996.

Fig. 5.04 *Helicopter-aided gully cleaning to reduce volume of logging-introduced woody debris. Photo courtesy of FERIC*

Additional Comments:

- Consultation with a qualified registered professional is recommended before any gully cleaning is considered.

5.3.2 Slope Stabilization in Gully Areas

Objectives: To stabilize gully sidewalls, headwalls and adjacent slopes through the use of landslide rehabilitation, road deactivation, and/or revegetation techniques. Slope stabilization is critical to reduce the likelihood of channelized debris flows. Slope failures with volumes as small as 10 m^3 have been found to initiate these events in coastal B.C. (Millard, 1999). Headwall slope failures, in particular, appear to have the most potential to initiate a channelized debris flow in Coastal gullies. Although slope stabilization efforts in gully areas can be very costly due to safety and logistical factors, the cost-benefit may be justified when risk is considered (i.e. gullies commonly have a high hazard and high connectivity to aquatic resources). For gully features developed in highly erodible materials, an appropriate objective of rehabilitation may be to limit retrogression of the headwall and/or nick points.

Descriptions: A number of activities can contribute to an increase in the slope stability of gully areas. Landslide rehabilitation techniques, including headscarp stabilization, can reduce the potential for additional failures from entering the gully channel and initiating a debris flow. See Section 4.3.1 for a discussion of possible treatments.

Road crossings on the mid to upper portions of gullies are often sites of instability due to extensive introduced fills, or due to culverts or bridges that are prone to blockage. Where gully assessments indicate a high upslope debris flow potential or high debris flow initiation potential, these crossings should be adequately deactivated by either fully restoring the gully channel or ensuring that the crossing is made safe from potential channelized debris flows or debris floods (see Section 3). Road systems crossing gullies also commonly direct off-site drainage water into gully channels. For small diverted flows, this may have a limited effect on the hydrology and stability of the gully system. For large diverted flows that may have been pirated from adjacent areas of the hillslope or from adjacent watershed sub-basins, the change in hydrology can increase the gully hazard significantly. Restoring hillslope drainage paths by appropriate road deactivation upgrade of the gully crossing may reduce this hazard.

Hillslope stability can also be increased through revegetation with woody species, especially deeper-rooting conifers. Soil strength is enhanced through physical-mechanical effects and through hydrologic effects (see Figure 4.10).

Retrogression of small headwall areas underlain by erodible materials may be treatable by construction of structures as shown in Figure 4.09. A combination of filter fabric and coarse rock are used to mitigate the erosion.

For in-channel water management of gullies, it may be beneficial to install structures such as check dams where the channel is eroding into deep surficial deposits. Where expected flows are not high, soil bioengineering structures such as live gully breaks (Figure 5.05) and gully training fascines may be appropriate to reduce flow velocities and

channel erosion (see Section 6). Consultation with a qualified registered professional can provide guidance about the potential benefits of such actions.

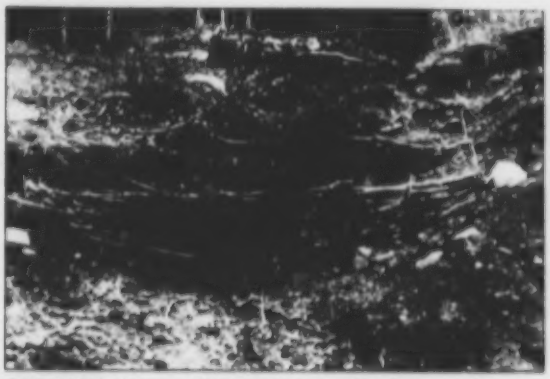


Fig. 5.05 *Live gully breaks installed on small gully, Dawson Creek Forest District.*

For gully systems that are considered to have a high likelihood of channel avulsion, channel stabilization may be warranted. Stabilization may include excavation to increase channel incision, armouring to protect sensitive channel sidewalls or beds, or planting and/or soil bioengineering to increase streambank stability (see Section 5.3.4). Any instream works may require agency approvals as discussed in Section 8.

Prescription Indicators: Any of the following features may warrant treatments to increase slope stability where there is potential for initiation of a debris flow or debris flood, or to mitigate erosion and sediment transport:

- unstable fills in gully crossings
- blocked culverts
- concentrated road drainage discharged onto gully sidewalls
- active sidewall or headwall failures
- unvegetated gully sidewalls or headwalls

Suggested Implementation Tips:

- Road deactivation of gully crossings should be completed when debris flow/flood and avalanche hazards are low. See Section 3.6.1 for additional information on road deactivation in gullies.
- Any prescriptions developed for treatment of sidewall or headwall failures should be in conjunction with a GAP and LRAP.

Cost Factors: Site specific.

Additional Comments:

- Road deactivation costs for gully crossings are site specific but often include added machine time for multiple handling of material and endhaul. For high risk sites, the added costs are usually warranted (i.e. the rehabilitation of gully crossings generally provides the most 'bang for the buck' with respect to road deactivation).
- Stabilization of active sidewall or headwall failures that have initiated debris flow events in the past should consider current hazards. In general, the first debris flow that passes through a gully system will transport the largest amount of debris and result in the greatest degree of sidewall scouring.
- Treatment selection will be dependent on both the hazard (e.g. mass wasting as in a debris flow, or erosion and sediment transport) and the nature of the substrate. For

erosion control in erodible substrates that are amenable to revegetation, treatments such as soil bioengineering and planting that provide rooting and matting benefits may be appropriate. For compact substrates that are not easily penetrated by plant roots, the use of rock or man-made products may be more effective for erosion control.

5.3.3 Mitigation Structures

Objectives: To mitigate the consequence of a debris flow or debris flood. A thorough discussion of the viability, limitations and conceptual design of such structures is provided in the Ministry of Forests Working Paper entitled "Debris Flow Control Structures for Forest Engineering" by VanDine (1996)

Descriptions: The primary function of control structures for gullies is to constrain or contain the coarse-grained component of the debris flow. Examples of such structures are shown in Figure 5.06. Unless the hazard is reduced or eliminated, such structures generally require periodic inspection especially following events. Repair or maintenance to remove accumulated sediment or debris may also be necessary.

Prescription Indicators: Installation of a control structure may be an option in cases where high hazard of debris flows cannot be practicably reduced and the consequence to downslope resources is high. These types of structures require assessment and design by qualified registered professionals.

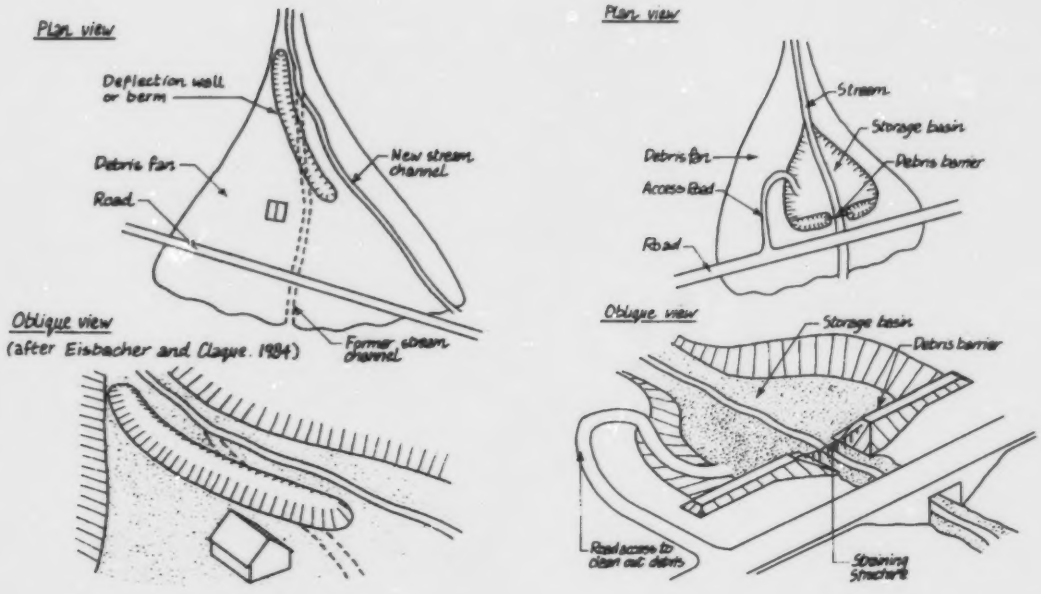


Fig. 5.06 Debris flow mitigation structures (from VanDine, 1996).

Suggested Implementation Tips:

- Construction supervision by a qualified registered professional recommended.
- Construction should only be carried out during dry conditions when debris flow and avalanche hazards are low.
- See VanDine (1996) for additional information on construction considerations.

Cost Factors: Costs will be site specific.

Additional Comments:

- Mitigation works should only be considered when review by a qualified registered professional has determined that such works are warranted based on an assessment of risk.
- Mitigation structures should be inspected on a regular basis and any required repair or maintenance carried out.

Fig. 5.07 Debris flow deflection berms at Port Alice, Vancouver Island.

5.3.4 Revegetation

Objectives: To minimize erosion and subsequent sediment delivery to aquatic habitat by revegetating gullies that have been affected by mass wasting events. Gullies often provide a direct connection to streams and eroded sediments can easily be transported to these streams.

Descriptions: One of the simplest means of reducing the erosion of exposed soils is to establish a vegetation cover. A general discussion of revegetation is presented in Section 4.3, while details of soil bioengineering treatments are provided in Section 6.

Upslope reaches of affected gullies typically show deep scouring. Mineral soils along sidewall and headwall areas are usually absent with parent material and/or bedrock exposed. In most cases, the steep slopes and compacted surfaces associated with these sites are best treated with hydroseeding, if treated at all. Access problems make ground

based hydroseeding impractical except at road crossings. Although heli-hydroseeding of gullies can be difficult and costly, it is arguably the most effective means establishing an initial cover on exposed gully sites.

The development of an effective root network by woody species on gully sites can increase soil strength and reduce erosion. Pioneering woody vegetation including alder, willow, and a variety of shrub species can form a dense network of roots that will help to support the steep slopes associated with most gullies. Where a successional reclamation approach (Polster, 1989) is used in the development of the initial seeded cover, native woody species will quickly invade. This process can be expedited, however, by the inclusion of seeds of woody species such as alder during initial seeding.

Planting on disturbed gully sites can also be used to establish woody species. Where soils are only minimally disturbed and the original soil profiles are still in place, planting with the species that would be prescribed for the adjacent slopes may be appropriate. However, where sites are significantly disturbed and where the original topsoil is lost, planting should focus on pioneering species such as alder, poplar, willow and red-osier dogwood. These and other pioneering species will help to ameliorate the harsh conditions of severely disturbed gully sites and allow later successional conifers to eventually establish. Alder, including both sitka and red alder is particularly helpful in restoring damaged sites as these plants associate with nitrogen fixing bacteria and can greatly enhance site nutrient levels.

The establishment of strong, fast growing woody species can be used to help prevent gully sidewall failures that might lead to debris flow initiation. Where there is a likelihood of sidewall failure, planting of woody vegetation such as alder in a relatively dense pattern (1500 to 2000 stems/ha) may aid in reducing the hazard.

The fan zones of impacted gully systems are typically extremely fertile and natural revegetation generally occurs rapidly. Where deposition zones are recent and have not yet revegetated, effective treatments include dryseeding, fertilizing and planting with conifers. Planting and/or soil bioengineering can also be undertaken to enhance channel stability.

A landslide rehabilitation assessment (see Section 4) is recommended to aid in the development of any revegetation prescriptions.

Prescription Indicators: See Figure 4.05 for general recommendations on seeding and planting treatments.

Suggested Implementation Tips:

- Inappropriate seed mixes applied on steep and dense gully sidewalls may lead to the initiation of 'carpet-type' failures. These may, in turn, initiate snow slides and/or debris flows. To avoid this, seed mixes dominated by bunchgrassses should be selected rather than mixes dominated by sod-forming species. Care must also be taken to ensure that the seeded vegetation allows space for invasion by woody species and that a diversity of species is established that will lead to a diversity of rooting depths. Uniform rooting depth is undesirable as it may lead to the formation of a plane of weakness in the underlying soils.

- For gully reaches that are narrow and have mature timber adjacent, natural regeneration occurs more rapidly than in areas of immature forest due to natural restocking and supply of organic debris. Where downslope consequences are not high, it may be more practical to allow these zones to revegetate naturally. Handseeding these reaches with a non-competitive grass species such as hard fescue may be an inexpensive option to provide some erosion control yet still allow invasion of native species. The proximity of mature trees may make it unsafe to seed aerially.
- Other revegetation treatments that may be applicable for scoured sidewall and headwall areas are planting with species such as alder and installation of soil bio-engineering structures. Modified brush layers can be used on gully sidewalls to provide roughness and reduce the potential for slides. Live staking at the base of gully sidewalls with species such as willow can create a strong and resilient root network that will help to reduce undercutting of the sidewalls.

Cost Factors: Seeding costs will be dependent on the application method, application rate, product specifications, prevailing product prices, access and size of the project. There may be added costs for planting and soil bioengineering if specialized safety equipment is required.

Additional Comments:

Gullies scoured by debris flows present significant challenges for revegetation as the substrate can be extremely variable passing from bedrock to basal till to organic-rich debris over short distances. For this reason, the cost-effectiveness of blanket-type treatments such as aerial hydroseeding may not be optimized.

5.4 Regional Factors

Coastal gullies generally have a higher frequency of debris flow and debris flood occurrences and should be managed and/or rehabilitated accordingly. Interior gullies, on the other hand, can often pose a higher risk from sediment delivery as they are commonly developed in erodible fine-grained surficial materials. While installations such as live gully breaks or check dams are generally not applicable on Coastal gullies with high stream flows, they may be appropriate for many Interior gullies especially where underlain by erodible soils.

Snow avalanches may affect both Coastal and Interior gullies. In some areas, snow avalanche may not be a concern if confined to a well-defined or incised track. However, the increased snowmelt may increase the potential for debris flows or debris floods to develop downstream.

Cleaning woody debris from gullies is generally more appropriate on the Coast to reduce potential debris flow or debris flood volumes. Gully cleaning is a very costly and often dangerous activity and should only be prescribed where it is clearly justified by a comprehensive risk assessment.

Revegetation treatments and species selection will be dependent on biogeoclimatic factors and by local site factors.

Although the GAP is not required for Interior gullies, all or specific portions may be applicable to Interior sites. Consultation with Regional specialists regarding its use is recommended.

6.0 Soil Bioengineering for Slope Stability

6.1 Introduction

Soil bioengineering can be an effective means of treating eroding surfaces and unstable surficial soil layers in the forest environment. Soil bioengineering is a term that describes the use of living plant materials to build structures that provide slope support. A knowledge of slope stability factors are important for the proper assessment of these sites and in the prescription of appropriate soil bioengineering structures. The intent of this section is to:

***Fig. 6.01** Installing soil bioengineering structures on a steep slope.*

- Provide some background on the principles of soil bioengineering;
- Discuss what site information is required during field assessment to develop an appropriate soil bioengineering prescription;
- Describe and illustrate many of the proven soil bioengineering structures that may be applicable to forest sites;
- Provide practical advice for prescription development and implementation; and
- Discuss treatment costs and treatment cost factors.

There are a variety of soil bioengineering structures that can be used to rehabilitate unstable and/or erodible sites. These can be used in the treatment of landslide scars, torrented gullies, and both deactivated and active roads, as well as several types of riparian and watercourse sites. The techniques that have been developed for use are described below in Section 6.3; however, there are opportunities to develop new techniques to address site problems. Several of the techniques described have been developed recently in British Columbia during the WRP and other programs.

Soil bioengineering uses live cuttings to build structures such as low slope support walls, drains and slope breaks. Some structures initially provide physical support against shallow slope movements, while others may act to mitigate the erosional effects of surface runoff. This usually results in a slope that promotes natural or applied revegetation processes. Over time, effectiveness of the structure is reinforced as the cuttings sprout and grow. Eventually the vegetation itself takes over the function of supporting the slope by lending mechanical strength (e.g. matting effect, root reinforcement, anchoring, buttressing) as well as providing hydrologic benefits (e.g. interception, protection) that may promote greater slope stability.

Soil bioengineering can be particularly useful in treating forest sites because:

1. The construction materials are natural and compatible with the surrounding natural environment.
2. The vegetation established encourages invasion by other vegetation, thus returning the site to a natural condition.
3. Work can generally be conducted by hand avoiding problems of machine access.
4. The effectiveness of soil bioengineering work can be realized within a relatively short timeframe.
5. The treated site becomes increasingly more stable as the vegetation establishes.
6. Costs may be a fraction of comparable engineering solutions.

Sites where soil bioengineering treatments may be applicable are those where:

- deep-seated slope instability is not an issue (to provide the greatest benefit, the rooting depth of the plant material should penetrate as far as possible into stable substrate);
- normal seeding and/or planting of woody species fails to achieve a satisfactory vegetation cover; and
- there is an expectation that the seeded cover will degrade over time without some further treatment.

Soil bioengineering can be used to treat sites where the surface instability is preventing plant growth. **Where the failure surface is greater than about 1 m deep, then other techniques should be considered for stabilization.** Live pole drains, however, can be used to drain large slump blocks where excess soil moisture is contributing to instability. Care should be taken when there is active mass-wasting upslope of the site being treated as the soil bioengineering works may be buried.

Soil bioengineering treatments utilize the strength in numbers concept. For example, the objective is not to create one large strong structure at the base of the slope to hold everything, but to develop enough structures on the slope so that together they treat the problem. This means the failure of a single structure does not result in failure of the entire system.

Soil bioengineering systems may also be used in conjunction with engineered treatments. Riprap may be specified, for instance, to protect a steep sided gully crossing with fluctuating water levels. The riprap can be brought up to the expected high water level with some freeboard while soil bioengineering can be used to treat the remainder of the slope. Living plants can also be used to strengthen engineering systems in a process known as biotechnical slope stabilization. For example, live cuttings installed in the spaces between riprap pieces may enhance the strength of the riprap. It may also allow for smaller sizes of riprap to be used (Schiechtl and Stern, 1997).

6.2 Assessment Procedure

Sites such as landslides, road cutslopes and fillslopes and other unstable sites should be assessed to determine if soil bioengineering is an appropriate treatment. For landslides where soil bioengineering might be considered as an option, an LRAP or similar procedure (see Section 4) should be conducted to provide the basic physical and biological site information. Specific

questions that need to be considered for the development of a soil bioengineering prescription include:

- What physical factors are preventing vegetation from establishing? It is paramount that the physical site factors limiting vegetation are identified and the soil bioengineering treatments designed to overcome these factors. Typical limiting factors include surface instability, rapid erosion rates, or dense compact substrates on steep slopes. Specific soil bioengineering structures have been developed to address each of these conditions.
- What climatic factors might be inhibiting vegetation growth? A lack of moisture or a southern exposure, for example, can significantly limit natural vegetation growth.
- Might soil bioengineering treatments reduce the cost of stabilization? In some cases soil bioengineering techniques can be used in conjunction with road construction activities to reduce the amount of material that must be moved to create a stable fillslope or cutslope.

Where geotechnical assessment has indicated potential for additional large failures on a site, soil bioengineering can not be expected to address these problems directly. In general, soil bioengineering will not be effective on sites where the movement of materials is greater than about 1 m deep (i.e. beyond the rooting depth of the plants used). For example, soil bioengineering treatments such as live pole drains can only be expected to provide limited water management benefits for all but the smallest rotational failures (e.g. debris slumps, earth slumps). Where machine access is possible and a reasonable amount of machine work will stabilize the slope, soil bioengineering should be given less consideration as a treatment option.

Personnel with an intimate knowledge of soil bioengineering should carry out the assessments. As soil bioengineering involves working with living materials, a background in biology or agriculture is helpful, although not essential. Similarly, a background and understanding of slope stability assessment and soil mechanics is essential in selecting appropriate techniques.

In prescribing soil bioengineering, site measurements such as slope gradients and approximate dimensions of the treatment area can be helpful to determining the quantity of soil bioengineering structures needed. Detailed surveying is generally not required. In many cases, however, the actual extent of the soil bioengineering will depend on the site conditions when the work is carried out. Prescriptions should, therefore, have a degree of flexibility to accommodate changes in factors such as site moisture. A prescription made during a dry period to use live pole drains, for example, may have to be modified to incorporate live gully breaks if installation occurs under extremely wet conditions. A sketch of the site showing the proposed location of the soil bioengineering structures is usually useful. Marked photographs showing the sites to be treated can be useful for developing appropriate prescriptions as well as for locating and implementing the prescribed works.

Identification of a source of cuttings during the assessment is an important part of planning a soil bioengineering project. Ideally, cuttings should be collected from areas that approximate the ecological conditions of the site being treated and are typically within 300 m elevation of the site and within 100 km in plan distance.

6.3 Soil Bioengineering Treatments

The following sections describe a number of soil bioengineering systems that can be used in hillslope restoration. Systems designed for treatment of steep slopes are presented first. These are followed by systems that can be used for soil reinforcement, water management and riparian restoration. Plant materials used in soil bioengineering systems and site factors to be considered are discussed in Section 6.4.

6.3.1 Soil Bioengineering Systems for Steep Slopes

6.3.1.1 Wattle Fences

Objective: To establish vegetation by reducing the effective slope angle through the construction of minor slope breaks. The wattle fences serve to catch ravelling materials. As the living cuttings used in construction sprout and grow, the wattle fences provide a cover of pioneering woody species on the slope. Where sites are moist, wattle fences can hold soils in place while allowing moisture to drain.

Description: Short (20 cm to 30 cm tall) retaining walls built of living cuttings (Figures 6.02 and 6.03). The cuttings, typically willow, red-osier dogwood and/or cottonwood, are placed horizontally on the slope behind rebar posts. Where soils are not dense and compact, living cuttings can be used as posts. Native soil is backfilled behind the wall of cuttings to form a small terrace or bench.

Prescription Indicators for Wattle Fences:

- Wattle fences are effective for treating steep cutslopes or landslide scarps.
- Sites where rolling/ravelling materials combined with moist conditions prevent growth.
- Steep slopes where surface erosion is preventing plant growth.
- Sites with fine-textured soils and ample summer moisture to allow plant growth.
- Slopes that are globally stable but where slope angles exceed about 75% such as steep cutslopes in stable materials (e.g. dense tills).
- Small (approximately $\leq$1 m deep) rotational failures and soil slumps can be treated with wattle fences to provide support of both the toe and headscarp.

Suggested Construction Tips for Wattle Fences:

- Sites for wattle fences must be moist enough to prevent the cuttings used on the face of the fence from drying out.
- Wattle fences are most easily constructed from the bottom of the slope to the top, thus giving workers a bench to stand on while the next fence is constructed.
- The row of posts (rebar should be 1 m long by 15 mm diameter) is established in the ground initially, followed by placement of the cuttings behind the posts. Cuttings should be in a single row on the uphill side of the posts. They should not be "woven" around the posts. The cuttings can be tied to the posts to hold them in place while the fence is backfilled.

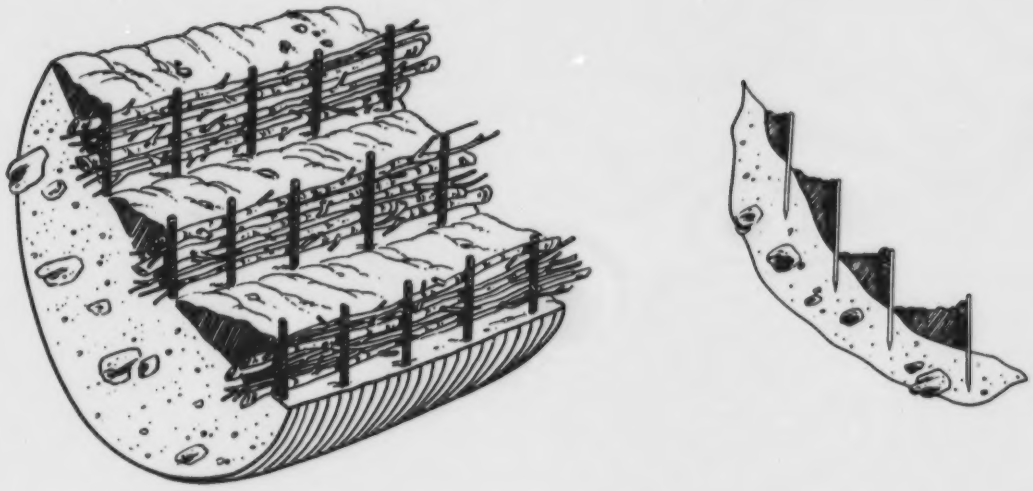


Fig. 6.02 *Wattle fences are short retaining walls constructed of living cuttings. They are used to provide terraces that will support plant growth where eroding oversteepened slopes are limiting plant establishment. The section on the right shows the spacing of wattle fences with increasing slope gradient.*

- Additional cuttings can be added to achieve the desired height. Avoid making the wattle fences too high as this will lead to toppling failures.
- Stagger the ends of the cuttings so that the wall of cuttings becomes an integrated structure with no weak areas.
- Small branches and trimmings from the cuttings can be used with the backfill for sites that are very moist (e.g. flowing mud)
- If rebar support posts will cause perforation and spalling of the slope, they should be inserted perpendicular to the slope face then bent upward to support the fence.

Fig. 6.03 *Wattle fences were used to treat this steep sand cliff at the University of British Columbia in 1989. The untreated area can be seen behind the worker. The area treated with wattle fences provides a good surface for plant growth. Willow from the wattle fences dominated the cover for about 8 years until alder and Douglas fir invaded the stabilized slope.*

Cost Factors: The following factors will tend to increase the cost of wattle fences.

- Density of the soil material.
- Difficulty of access.
- Steeper slopes (less slope area can be treated per unit of fence constructed).
- Lack of suitable plant materials nearby.

Additional Comments:

- In silty materials and fine sands, wattle fences will allow moisture to drain from the face while holding the soil in place, thus enhancing the stability of the soil material.
- Wattle fences should not be used where soil materials are excessively coarse.
- Watering is sometimes used to aid in establishment of plant material in the wattle fences during the first growing season following construction.
- Growth of the cuttings used to construct the wattle fences increases the strength of the slope support.
- Experienced works crews will generally be more cost-effective for any type of soil bioengineering installation.

6.3.1.2 Modified Brush Layers

Objective: To form a small bench on the slope to stop the movement of ravelling material and thus allow plant growth. Living cuttings are used in the modified brush layer to establish pioneering vegetation on the slope.

Description: Benches are formed by a log or board placed horizontally across the slope and supported by two pieces of rebar or living stakes (Figures 6.04 and 6.05). Living cuttings are inserted above the log or board (normal sites), below the log or board (very dry sites) or with a small wattle fence below the log or board for drainage (wet sites).

Prescription Indicators for Modified Brush Layers:

- Steep ravelling or eroding slopes (road cuts and fills, landslides and gully sidewalls).
- Sites that are too dry for wattle fences.

Suggested Construction Tips for Modified Brush Layers:

- Working from the bottom of the slope upward, install two rebar (1 m long by 15 mm diameter) posts about 1 m apart.
- Centre a 2 m long log (min. 20 cm diameter) or board (min. 5 cm by 20 cm, 2 by 8 rough cut) on the upslope side of the rebar and excavate material from behind the log or board to backfill.
- Backfill until a slightly sloping (2% to 5% into the hill) bench is created.
- Plant living cuttings (min. 40 cm long by 1.5 cm diameter) a minimum of 30 cm deep and 5 cm to 10 cm apart on the bench. The cuttings should be perpendicular to the surface of the original ground.
- Cuttings should be buried for 90 percent of their length and should extend beyond the edge of log or board slightly.

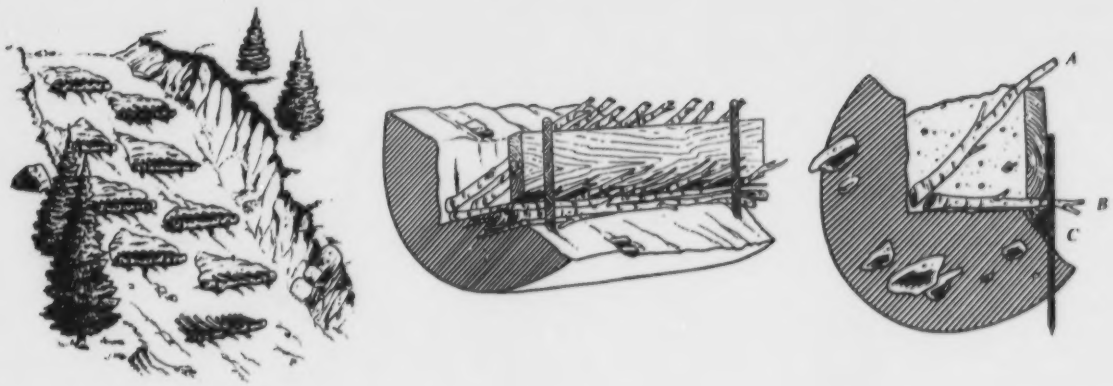


Fig. 6.04 *Modified brush layers can be built with either a log or a board for support. They should be staggered across a slope so that any material rolling down the slope can be caught. The detail shows a modified brush layer prior to backfilling, while the section shows the normal backfill that creates a narrow bench. On mesic sites the cuttings should be placed so that they extend above the board, while on very dry sites cuttings should be placed below the board to take advantage of any shade. On very wet sites a few horizontal cuttings can be laid below the board to act as a drain.*

- On very dry sites, cuttings should be placed below the board or log prior to backfilling. On wet seeping sites, a short wattle fence can be built against the rebar below the log or board.
- Compact backfill securely around cuttings to ensure that no air pockets remain.
- Do not use rock or coarse material for backfill.

Fig. 6.05 *Growth of cuttings in a modified brush layer as well as the initial bench formed on the slope serves to control erosion and ravelling.*

- Avoid undercutting the slope during backfilling operations. Uniformly scrape backfill from the surface of the slope without creating additional oversteepening upslope.

Cost Factors: The following factors will tend to increase the cost of modified brush layers.

- Density of the soil material.

- Difficulty of access.
- Composition of soil materials. Coarse rocky soils will be more difficult to work with than finer textured soils without rocks.
- Lack of suitable plant materials nearby.

Additional Comments:

- Modified brush layers can be used on dry ravelling road cutslopes to prevent ravelling materials from filling the ditch and thus reduce maintenance costs.
- Use cuttings to support the modified brush layers on very loose soils where the rebar would not hold well.
- Moisture retaining polymers have been added to modified brush layers where dry conditions have been encountered. Peat moss has also been used to help retain moisture.
- Electric rebar drivers (like jack hammers) can be helpful where large numbers of modified brush layers are being installed. These can be powered by a small gasoline powered generator.
- Where timing constraints dictate, the rebar and board/log portion of the modified brush layers can be constructed initially and the living cuttings can be added later during the dormant season.
- Suitable slab wood can be used in lieu of either the log or board for support of the structures. Be sure to maintain the minimum dimensions.
- Two rough cut 2 x 4's can be used with cuttings placed between the 2 x 4's as well as above or below.

6.3.1.3 Brush Layers In A Cut

Objective: To establish a row of living, woody plant materials across a slope. Once they grow, brush layers in a cut (in-situ materials) can assist in trapping ravelling materials.

Description: Brush layers in a cut consist of a row of cuttings (40 to 50 cm long by 1.5 cm min. in diameter) placed in a trench excavated along the contour of the slope (Figures 6.06 and 6.07). The cuttings are planted deeply so that only 10 % of their length protrude from the slope.

Prescription Indicators for Brush Layers in a Cut:

- Ravelling or eroding landslide or gully sidewall slopes where vegetation has failed to establish.
- Relatively dry sites that would be too dry for wattle fences.
- Landslide scars and road cuts where native materials are eroding and preventing natural vegetation growth.

Suggested Construction Tips for Brush Layers in a Cut:

- Working from the bottom of the slope, dig a bench or trench about 40 cm wide across the cut and sloping into the hill. Wider benches may be used on

Fig. 6.06 Brush layers in a cut can provide a row of living plant materials and assist in preventing movement of surface materials.

sites where longer cuttings are to be inserted for structural reasons or due to lack of moisture.

- Install cuttings (min. 40 cm long by 1.5 cm diameter) 5 cm apart on the bench and backfill by drawing material from above or use the excavated material from the next trench upslope to backfill.
- Cuttings should have at least 90% of their length buried.

Cost Factors: The following factors will tend to increase the cost of brush layers in a cut.

- Density of the soil material (time required to dig the trench or bench will increase where soils are dense).
- Steep slopes will increase installation time and may require the use of climbing harnesses.
- Composition of soil materials. Coarse rocky soils will be more difficult to work with than finer textured soils without rocks.
- Lack of suitable plant materials nearby.

Additional Comments:

- Brush layers in a cut do not provide an initial bench like wattle fences or modified brush layers and will therefore not be effective initially for slopes with ravelling materials.
- The large volumes of material that must be excavated for the installation of brush layers in a cut make this technique relatively costly.
- Placement of the cuttings well into the hillslope increases the probability of intersecting moist conditions which will increase the chances for successful establishment.

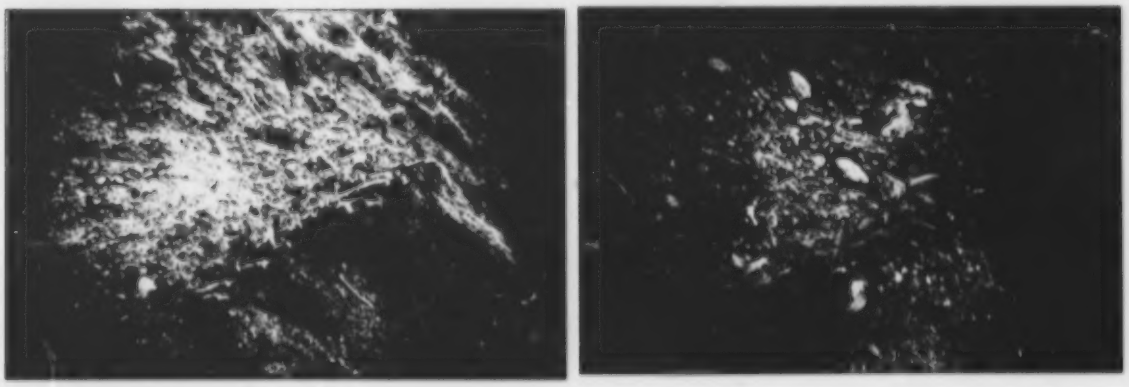


Fig. 6.07 *Brush layer in a cut two weeks after installation (left) and five weeks after installation (right).*

6.3.2 Soil Bioengineering Systems for Soil Reinforcement

6.3.2.1 Brush Layers In Fill

Objective: To reinforce uncompacted or marginally compacted fill materials by providing shear resistance against shallow rotational failures within constructed fillslopes. The cuttings themselves provide initial physical reinforcement with subsequent added reinforcement as they root along their entire lengths.

Description: Brush layers in fill consist of full length (3 m to 4 m or longer) cuttings placed in the fill material as the fillslope is constructed (Figure 6.08). The cuttings do not need to be trimmed, except near the tip, as the twigs and branches can be incorporated into the fill to provide additional live woody material. The tips of the cuttings protrude from the fill material to allow the cuttings to sprout and grow.

Prescription Indicators for Brush Layers in Fill:

- Construction of large volumes of loose fill such as may occur during road construction.
- Sites where oversteepening the fill would reduce the need for end hauling, such as on partially pulled back roads.
- During road construction where slightly oversteepening the road fill material will allow the fill to blend into the existing slope avoiding creation of large sliver fills.

Suggested Construction Tips for Brush Layers in Fill:

- A good supply of cuttings must be available since this technique requires large quantities of cuttings.
- Brush layers in fill are constructed with the same equipment used to build fillslopes (e.g., excavators, trucks and bulldozers, scrapers, etc.).
- A layer of cuttings (as long as possible) is placed on top of each layer of fill with about 20 cm of the top end (distal) of the cutting protruding from the fill.
- The cuttings are placed about 20 cm apart and are buried by the next layer of fill.
- Trim the top end of the cutting so that it is no smaller than about 1.5 cm in diameter prior to planting or leave the entire top of the plant protruding from the fill and trim later.
- Compaction using the back of the excavator bucket will help to ensure the fill material is in full contact with the cuttings.
- Fill slopes supported by brush layers in the fill have been successfully built with slope gradients of up to 110 %.

Cost Factors: The following factors will tend to increase the cost of brush layers in fill.

- Some down time for equipment may be necessary during placement of the cuttings. Locating prepared cuttings adjacent to the installation site will expedite the process and reduce costs.

- Steep inaccessible sites will result in higher unit costs.
- Lack of suitable plant materials nearby.

Additional Comments:

- Brush layers in fill provide an effective means of establishing vegetation on fillslopes and, in certain situations, may reduce the amount of required endhaul. Slopes at gradients of over 100 % can be established. This can be particularly valuable when dealing with steep gully crossings and other sites where complex slope conditions compound to create oversteepened slopes.

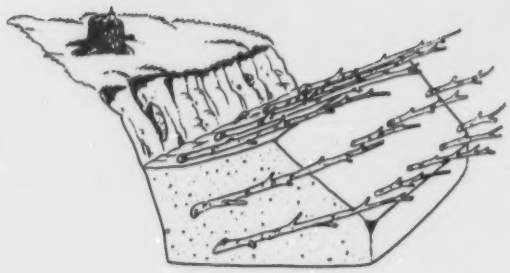


Fig. 6.08 *Brush layers in fill can act to reinforce the fill material. Full-length cuttings are used and can be expected to root along their entire buried length.*

- As most of the cuttings are below ground and therefore protected from drying out, brush layers in fill can be constructed at most times of the year. Avoid times when stored carbohydrate reserves are low (at full leaf extension) and the hormonal status of the plants is favouring shoot growth.
- The use of full size cuttings reduces the trimming required but cuttings are more bulky for transport. Some selective trimming may be practical.

6.3.3 Soil Bioengineering Systems for Water Management

6.3.3.1 Live Pole Drains

Objective: To manage small surface and subsurface flows. Live pole drains act as preferred conduits for soil moisture and can drain saturated soils quickly. They can also provide a coppice of hydrophytic vegetation on wet and seeping sites.

Description: Live pole drains are constructed of bundles of living cuttings placed in shallow trenches that are dug along the zones of groundwater seepage or surface flow in such a manner that the bundles intersect and collect the moisture (Figures 6.09 to 6.12). The bundles of cuttings are then lightly buried with local material, leaving some of the cuttings exposed on the top of the bundle. Careful trimming of the cuttings is not required. The small twigs and branches can assist in acting to filter out fines from the drain. The bundles should be tied as tightly as possible with twine or wire and should be a minimum of 30 cm in diameter when tied. They act much like conventional "French" drains.

Prescription Indicators for Live Pole Drains:

- Sites where flowing seepage is causing slope instability.

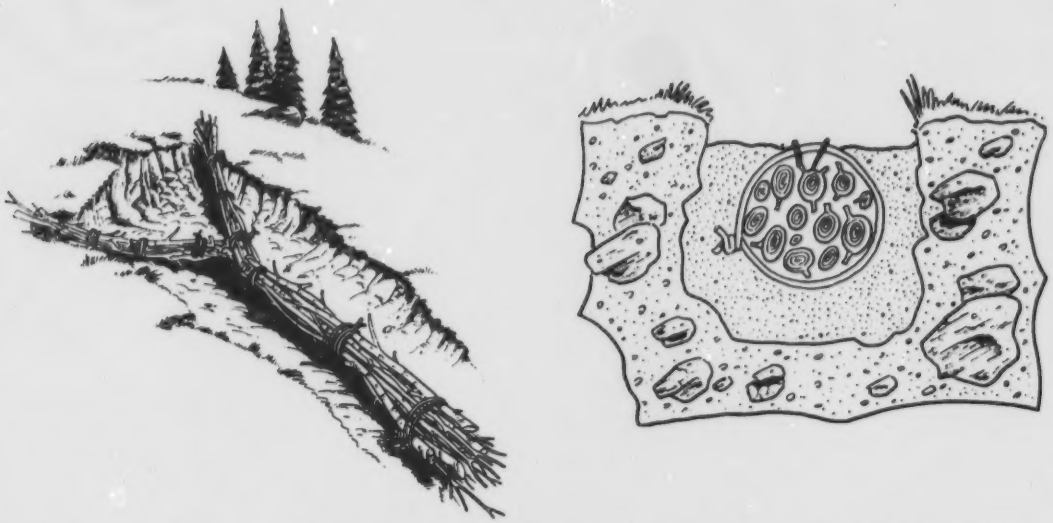


Fig. 6.09 *Live pole drains can be used to stabilize slumping soils. The view on the left shows the installation of live pole drains in a slump with the covering soils removed for clarity. The cross-section on the right shows a typical installation. Some twigs from the bundles should be left above ground.*

Fig. 6.10.

Fig. 6.10 *Construction of a live pole drain bundle at Km 13 on the Lower Burnt FSR near Chetwynd. Note how the branching pattern has been designed to collect water from a variety of seepage spots.*

Fig. 6.10 *Installation of the live pole drain bundle shown in Fig. 6.11 Shallow trenches were excavated in the saturated material. The bundle of cuttings provides a preferred flow path for water.*

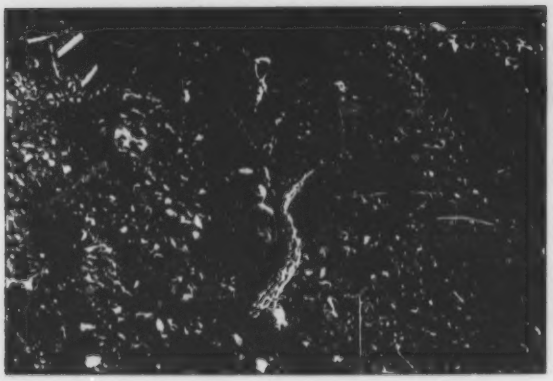


Fig. 6.11

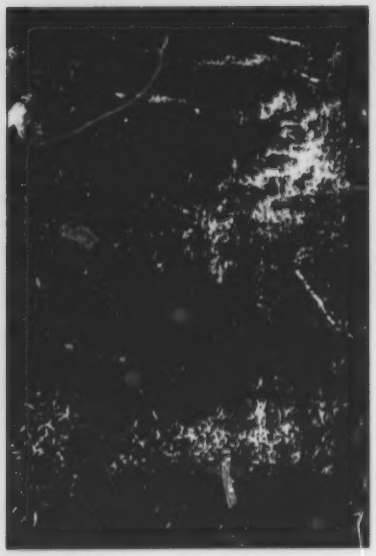


Fig. 6.12

Fig. 6.12 *Growth of the willows used in the live pole drain shown in Figs. 6.10 and 6.11 adds to the support of the slope by providing a network of hydrophytic plant roots.*

- Rotational failures and slumps caused by excess moisture that is relatively near the surface.
- Slumps that occur the first spring after road pullback due to saturated backfill in seepage zones.
- Sites where seepage is causing erosion and rilling on the slope below.
- Where water must be diverted at the top of a cutslope or landslide to increase slope stability.

Suggested Construction Tips for Live Pole Drains:

- Construct the bundles at a location where they can be easily assembled and then move the bundles to the site.
- Construction of large (30 cm diameter) tight bundles of cuttings is essential for the proper functioning of live pole drains.
- Alternate tips and butts and overlap cuttings for maximum effectiveness. Allow some of the twigs and stems of the cuttings in the bundle to be exposed.
- Cinch the bundles with rope or strapping and then secure with twine or wire.
- In digging the trench for the live pole drain, work downslope from the top of the site. Moisture should collect in the trench as it is being dug.
- Backfill with local native materials.
- Be sure to intersect the seepage areas fully so that moisture flows down the live pole drain.
- Live pole drains should be built to drain the slope quickly. Branching patterns can be used to catch diffuse seepages.

Cost Factors: The following factors will tend to increase the cost of live pole drains.

- Lack of suitable cuttings nearby.
- Nature of the site (rocky sites are difficult).
- Consistency of the soil material at the time of installation (it is harder to dig a trench at wet sites).
- Density of the soil material.
- Length of the live pole drain. Long drains are more difficult to transport to the installation site.

Additional Comments:

- Contour fascines are like live pole drains but are installed on the contour rather than down the slope. Contour fascines are used for drier sites to control sheet erosion and rilling.
- Gully training fascines are also like live pole drains, but are constructed along the edges of gullies to help reduce gully sidewall erosion and provide vegetation in the gully.

- Live pole drains can be used to intersect moisture along potential planes of failure, thus, reducing pore water pressure and increasing slope stability. They may provide a benefit even with relatively large blocks of unstable material.
- For sites where deeper installations are required, live pole drains can be built with one branch from each cutting extending to the surface. In this manner, live pole drains can be built up to 1 m below the surface.
- Live pole drains can be used in conjunction with a variety of other soil bioengineering structures including wattle fences and brush layers.
- A 30 cm thick layer of cuttings can be laid under fill material to act as a blanket drain. The ends of the cuttings must protrude from beneath the fill if they are to root. This is referred to as a 'live pole blanket'.
- A variety of drain patterns can be used as long as the water remains confined to the drain.
- Chevron shaped drains (pointing upslope) can be used to divert subsurface water away from unstable headscarp areas. Care is required to ensure that eventual discharge is onto stable terrain.
- Live pole drains installed in fine-grained soils may clog easily resulting in erosion adjacent to the clogged structure.

6.3.3.2 Live Silt Fences

Objective: Live silt fences are used to reduce sediment transport in slow moving streams and ditches. They should not be used in fish-bearing streams as the established vegetation may inhibit fish passage. Live silt fences provide a stand of hydrophytic vegetation in the ditch or stream and initiate the process of wetland establishment. They can also be used to manage sediment in ditches along active roads.

Description: Live silt fences are rows of cuttings inserted into the streambed approximately 3 cm apart to slow water velocities and cause sediment deposition (Figures 6.13 and 6.14). The cuttings will also trap small debris that will further slow the flow. As the cuttings grow, the water flow between the stems of the plants will lead to development of a brushy, swamp area characteristic of natural seepage areas and small streams. Species such as skunk cabbage soon invade these sites. Willow, red-osier dogwood and cottonwood cuttings are suitable for use in live silt fences as these species will continue to grow despite burial of their stems by sediment.

Prescription Indicators for Live Silt Fences:

- Ditches and small drainage courses where flowing water is carrying sediment or causing erosion.
- Cross-ditches on deactivated roads where erosion is a concern and armour rock is not readily available.
- Road drainage ditches on active roads where sediment transport is a concern.

Fig. 6.13 Live silt fences can be used to provide a willow coppice in small streams and ditches. They act by slowing the velocity of the water and allowing sediment to settle out. The cuttings can be either in single rows (as shown) or multiple rows in each fence.

- Natural gullies and drainage areas where harvesting impacts have created a sediment hazard.
- Flowing seepage areas that may be an erosion concern.
- Where additional sediment removal is needed at the inlets and outlets of sedimentation ponds and grassed swales.

Fig. 6.14 Live silt fence with established cuttings.

Suggested Construction Tips for Live Silt Fences:

- Cuttings at least 40 cm long and 1.5 cm in diameter should be used.
- Cuttings should be inserted for at least 3/4 of their length into the substrate. In dry ditches where flows are seasonal, insert cuttings 90% of their length into the substrate.
- Cuttings should be spaced about 3 cm apart.
- Ensure cuttings are established far enough up the banks of the channel so that the water will not flow around the ends of the installation and erode the banks.
- Two or three rows of cuttings can be used in each live silt fence.
- Pilot holes for cuttings can be made with a pry bar.
- Do not try to establish cuttings in dense substrates as root penetration will be limited.

- In some cases it may be easier to dig the cuttings into the substrate using a spade.

Cost Factors: The following factors will tend to increase the cost of live silt fences.

- Lack of suitable cuttings nearby.
- Nature of the site. Rocky sites or sites with dense substrates make installation difficult.
- Paying for the silt fences on a per cutting basis. Live silt fences should be costed based on an average size and average number of cuttings.
- Sites where additional sediment control is needed during installation of the live silt fences.

Additional Comments:

- Although live silt fences should not be used in fish-bearing streams, they are effective for tributaries to fish bearing streams.
- Wetlands that develop where live silt fences have been used can provide significant water purification functions, including de-nitrification and heavy metal sequestering.
- Care must be taken to ensure hydraulic integrity of sites where live silt fences are used. In general, they are appropriate only where water velocities are low.

6.3.3.3 Live Bank Protection

Objective: To protect vulnerable stream banks from erosion. It may also be applicable to stabilize the banks of torrented streams or mitigate the retrogression of channel nick points. Live bank protection can be used in treating roadside ditches and culvert inlets and outfalls where construction activities have left bare, erodible ditch lines. Installation of live bank protection in these situations can reduce maintenance requirements. The technique is especially useful where soils are fine-textured. Live bank protection may also be effective around ponds or lakes to protect the shoreline from wave action and provide riparian cover.

Description: Live bank protection is constructed along the edge of the watercourse (Figures 6.15 and 6.16). It is constructed of cuttings laid horizontally behind posts of live cuttings (where conditions permit) or rebar (where soils are dense) similar to wattle fences. Commonly, live bank protection is installed on the bends of a stream or ditch where undercutting is a concern.

Prescription Indicators for Live Bank Protection:

- Along ditches and drainage courses where the water flow is causing erosion.
- On steep-sided ditches to protect against bank collapse.
- Where constructed ditches traverse deep organic deposits and an open channel must be maintained.
- Along natural gullies where torrenting has left exposed erodible soils.

- Along constructed fish habitat to provide riparian cover and provide a slope break at the water level.
- Along the margins of cross-ditches on deactivated roads in place of armouring where seasonal flows may cause erosion.

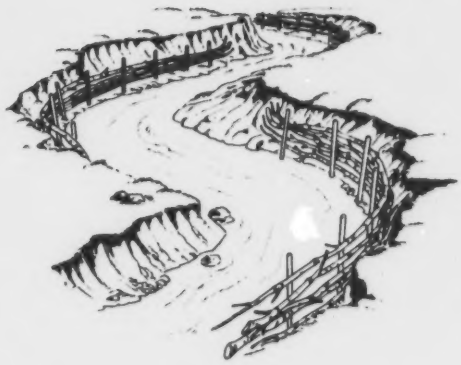


Fig. 6.15 *Live bank protection can be used to control undercutting and erosion in channels occurs. The backfill has been removed in these drawings for clarity. Typically, the undercut bank would be resloped to backfill the structures.*

Suggested Construction Tips for Live Bank Protection:

- Rebar posts or stout cuttings are established along the line where the live bank protection is to be installed.
- Position the upstream end of the live bank protection so that the possibility of undercutting of the structure is minimized.
- The ends of the live bank protection structures should be secured into the bank on the tangent between two curves of the stream to avoid erosion and potential removal of the structure.
- Cuttings are arranged behind (away from the water) the posts like a wattle fence being sure to overlap and alternate butts and tips for strength.
- Cuttings can be lashed to the posts to provide additional strength to the structure.

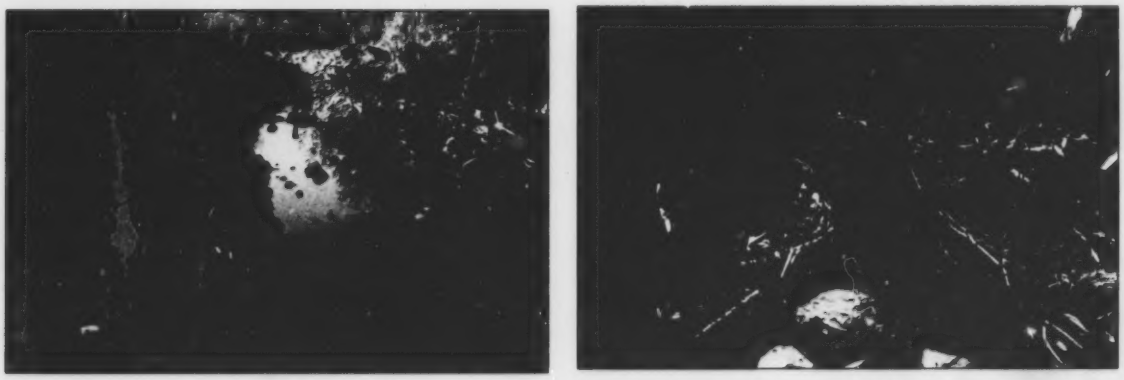


Fig. 6.16 *Live bank protection immediately after installation (left) and after establishment of cuttings (right).*

- Native material is backfilled behind the cuttings. Where materials are very fine, twigs and branches trimmed from the cuttings can be used to fill any gaps in the structure.
- Avoid backfilling with rock. Rock may be appropriate to protect the toe of the structure from scour.
- Two or more tiers of live bank protection can be used for high banks.

Cost Factors: The following factors will tend to increase the cost of live bank protection.

- Nature of the site. Rocky sites, shallow bedrock or sites with dense substrates make installation more difficult.
- Lack of suitable backfill on the banks of the channel will require materials to be imported.
- Sites where high stream flows make working conditions hazardous.
- Sites where the presence of fish requires working within fisheries windows and fish exclusion and salvage.
- Constraining installations to fisheries windows may necessitate the storage of plant materials.

Additional Comments:

- Improperly installed live bank protection can contribute to avulsion of the stream. If in doubt, consult with a hydrologist.
- Large diameter cuttings can provide good protection against erosion, although these are sometimes more difficult to work with.
- Incorporation of other suitable species of cuttings other than willow will increase the diversity of the established riparian vegetation.

The following additional soil bioengineering treatments have been developed to address specific conditions that have been noted at several riparian restoration sites.

Live palisades (Figure 6.17) are designed to provide a riparian cover of cottonwood trees adjacent to eroding banks. Note that it is important to have the large diameter (5 to 10 cm) cottonwood cuttings extend down into the water table so that these plants will have ample water. Smaller willow and red-osier dogwood cuttings can also be placed in the same trench. Where soils are reasonably fine-textured, these supplementary cuttings do not have to reach the water table, but where sites may be droughty, they should extend to the water table.

Pocket planting (Figure 6.18) and *Joint planting* (Figure 6.19) are both used where vegetation is desired on a riprapped bank. In pocket planting, soil is placed in the interstitial spaces between the riprap boulders and cuttings are inserted into this material. This is most easily done in conjunction with installation of the riprap but can also be done later by hand or with small equipments. Care must be taken to ensure that any filter fabric that might be under the riprap is breached to

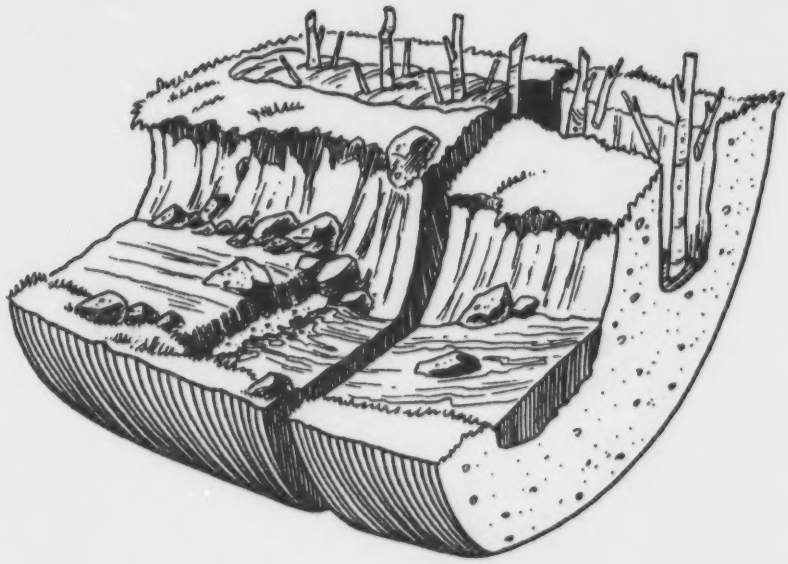


Fig. 6.17 *Live palisades consist of a row of large (5-10 cm diameter) cottonwood posts inserted into a trench dug along the top of the slope. The wall of cottonwood trees are intended to provide a structure that will help to reduce bank erosion. Large cuttings must extend down into the water table so that these plants will have ample water.*

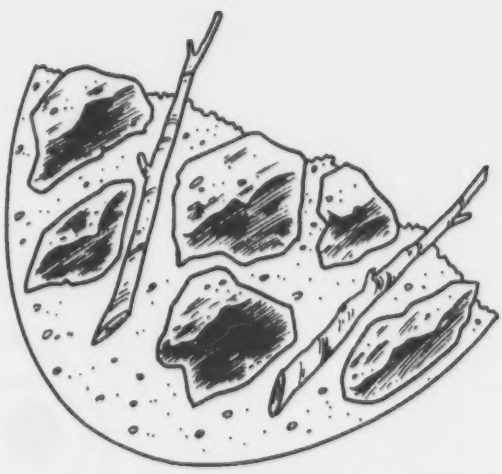


Fig. 6.18 *Pocket planting recreates the natural process of vegetation establishment in coarse boulders by providing a pocket of soil in which the cuttings can root and grow.*

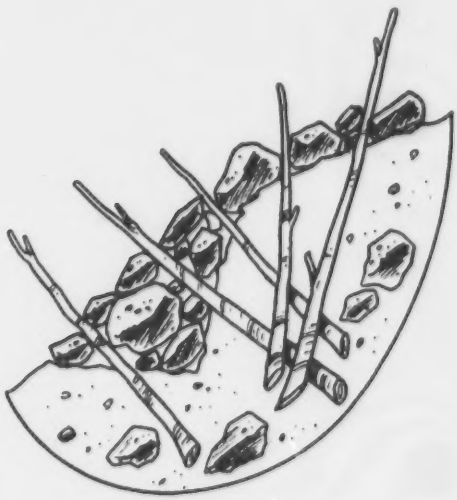


Fig. 6.19 *Joint planting consists of planting cuttings through the spaces between the rocks of the riprap.*

allow the roots of the plants to penetrate the underlying substrate. Joint planting is the establishment of cuttings in the substrate below the riprap without importing additional soil. . The cuttings are planted into the native soils under the riprap taking care to breach any filter fabric that may be present. Both joint planting and pocket planting will strengthen the riprap by slowing the flow of water across the rock surface and by helping to anchor and lock the riprap. Willow, cottonwood and/or red-osier dogwood can be used in either of these techniques.

All three of above treatments make use of natural successional processes to provide effective riparian cover. By establishing pioneering vegetation, the site is prepared for the subsequent establishment of later successional species.

6.3.3.4 Live Gully Breaks

Objective: To reduce gully erosion by slowing the stream flow. Temporary storage of sediment may also occur. Where gully torrents originate from minor collapses of gully sidewalls, live gully breaks may also assist in reducing the potential for these events.

Description: Live gully breaks are similar in construction to large wattle fences but are installed across the transport zone of the gully (Figures 6.20 and 6.21). For narrow gullies, the cuttings may be aligned pointing upstream so that they can be keyed into the sidewalls. When installed at appropriate intervals along the channel, they comprise a series of vegetated steps that control the stream velocity. To reduce the potential for small debris flows, live gully breaks may be established in the upper reaches of the channel or headwall where these events are most likely to initiate.

Prescription Indicators for Live Gully Breaks:

- Steep torrented gullies where vegetation is lacking. May not be appropriate where high flows are expected.
- Gullies in erodible materials where stream flow is continuing to erode the gully.
- Steep ephemeral channels where erosion may be a concern.
- Steep cross-ditches on deactivated roads where erosion might be a concern.
- Deeply-incised road ditches where check dams are needed to trap sediment and reduce erosion.
- Where water has eroded rills or swales on road cutslopes.

Suggested Construction Tips for Live Gully Breaks:

- Be aware of the dangers of working in gullies. Have a safety plan and establish wet weather shutdown procedures.
- Work upstream from the bottom of the gully.
- Focus on critical zones where small failures may initiate a debris flow.
- Live gully breaks must be securely established and appropriately located in the gully or channel to prevent dislodgement and channel avulsion.

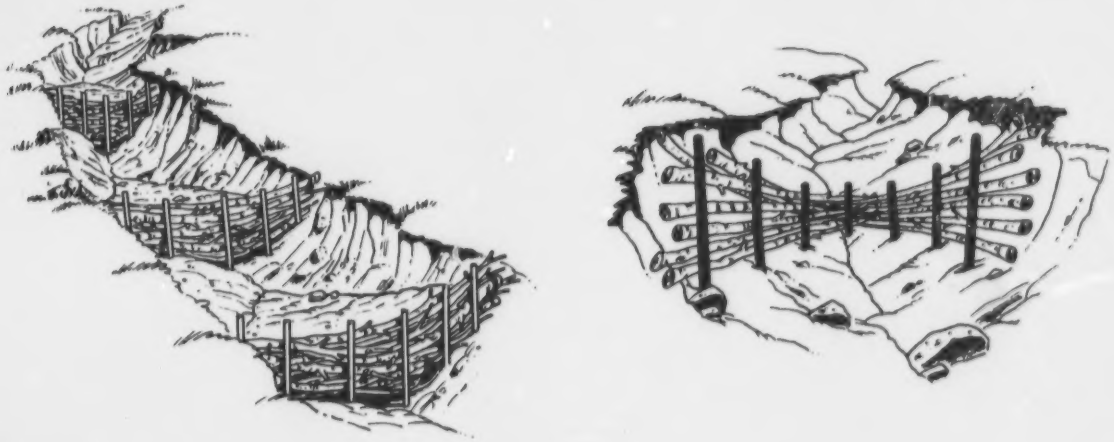


Fig. 6.20 Live gully breaks act to slow the water velocity and erosion in gullies. In narrow gully channels (right, view looking upstream) the structure points upstream with the cuttings crossed at the upstream end (backfill removed for clarity). In wider gullies (left) the structure is similar to a wattle fence installed across the gullychannel.

Fig. 6.21 Live gully breaks can control the flow of water in steep mountainous gullies and reduce erosion.

- The ends of live gully breaks can be dug into the banks of the gully to add strength.
- Large diameter cuttings can be keyed where the live gully breaks are not being curved to follow the gully sidewalls.
- Installation of a rock drain under the live gully break can provide for drainage during low flow periods.

Cost Factors: The following factors will tend to increase the cost of live gully breaks.

- Dimensions of the gully being treated (width and length of channel).
- Nature of the gully sidewalls. Steep, dense materials will be more difficult for installation.
- Lack of suitable backfill in the gully.
- Availability of suitable cuttings near the work site.
- Poor weather and the need for shutdowns.
- Steeper channel gradients will require more structures.

Additional Comments:

- Care must be taken to ensure that the installation does not result in channel avulsion or undercutting of sidewalls.

- Live gully breaks may be effective in controlling flow velocities and channel erosion. They may also be used remedially for eroding cross-ditches and ditch lines.
- The consequence of sediment retention in the structures should be assessed with respect to the probability of incorporation of this material in a debris flow.

6.3.3.5 Live Staking

Objective: To help stabilize the upper soil layer by providing an immediate buttressing effect and longer term rooting effects by using individual live cuttings. Live staking may also be used to "pin" sod or erosion control revegetation matting to a slope and create a diversity of rooting depths. It can be especially useful to provide cohesion in silty soils that are prone to earth flow movement where the stakes can be easily inserted and root quickly. Live staking can be used as an inexpensive means of quickly establishing pioneering woody vegetation.

Description: Living cuttings are used in live staking and are inserted into the soil so that at least 75% of the length of the cutting is underground (Figures 6.22 and 6.23). On drier sites, approximately 90 % of the cutting may need to be inserted. Cuttings need not be inserted vertically (as shown) but can be placed diagonally into the soil as long as the cutting will remain moist over most of its length. Live staking can be installed singly or in groups of stakes to create a specific effect such as the creation of wildlife habitat or a dense stand of willows on a wet seepage site.

Prescription Indicators for Live Staking:

- In any situation where the inclusion of woody vegetation would help increase the soil stability.
- Steep cutslopes on active roads where woody vegetation will trap ravelling material before it blocks the ditch line..
- Where wet seeping sites require a pioneering cover.
- Where stream banks require riparian vegetation.
- Where steep unvegetated fill slopes require woody cover to slow the movement of materials downslope.
- To increase the rooting strength in the backfill behind wattle fences, live gully breaks and live smiles.

Suggested Construction Tips for Live Staking:

- Cuttings should be a minimum of 40 cm in length and 1.5 cm in diameter. Larger diameter cuttings have greater carbohydrate and moisture reserves and tend to grow better than smaller cuttings.
- The spacing between cuttings can vary widely depending on the use that is being made of them. Where saturated mud is being treated, 10 or 20 cm spacing between cuttings is suitable; where sod is being staked, a 1 m spacing is ample.

- In soft soils, cuttings can be pushed in by hand or driven in with a rubber mallet. For denser substrates, a pry bar can be used to provide a pilot hole for the cuttings. An electric jack hammer may be required where the substrate is very dense.
- Avoid splitting or damaging the top end of the cuttings. Trim damaged cuttings with shears to avoid desiccation.
- Tree planter bags can be used to carry cuttings on the slope.
- Cuttings should be planted with the proximal end (butt) down into the soil and the distal (top) end up. Careful study of old leaf scars can be used to determine the distal and proximal ends of the cuttings. The leaf scars "smile" when they are correctly oriented.
- Longer (1 m) cuttings can be used to provide deeper rooting where necessary.

Cost Factors: The following factors will tend to increase the cost of live staking.

- Dense substrate.
- Length of the cuttings required. Longer (1 m) cuttings will cost more than normal (40 cm) sized cuttings.
- Lack of suitable cuttings nearby.
- Number of cuttings being installed. An economy of scale can be achieved where large numbers of cuttings are being used.
- The conditions of the site. Where the site is rugged and access is difficult, costs will escalate.

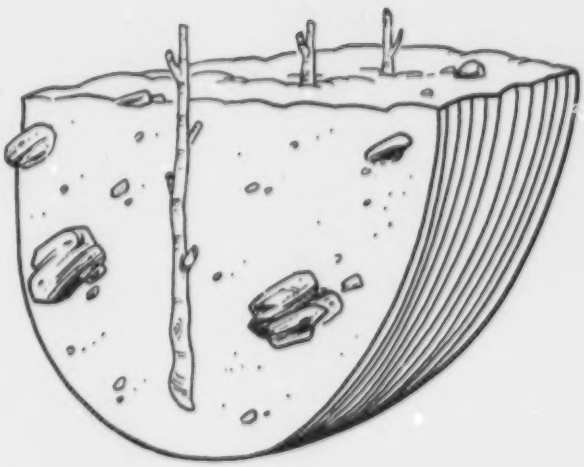


Fig. 6.22 *Live staking is a simple method of establishing pioneering woody vegetation. It can be effectively used on "flowing" silts, to stake down sod and to establish riparian vegetation along streams.*

Fig. 6.23 *Live stake flushing out and rooting.*

Additional Comments:

- Live staking can be an efficient means of establishing woody species on restoration sites and should be considered as an adjunct to all soil bioengineering projects.
- Live staking can be a good activity for community groups, school groups and others that may wish to be involved in the restoration work.
- Collection of cuttings in the late winter and storage in snow banks on north-facing slopes can be an effective means of ensuring that suitable cuttings are available for work later in the season.

6.3.4 Soil Bioengineering Systems for Riparian Restoration

6.3.4.1 Live Shade

Objective: To regulate water temperature and provide a rapid and inexpensive vegetative cover on newly constructed fish habitat. Live shade provides riparian cover quickly in areas where vegetation has been removed during construction.

Description: Live shade consists of a tripod constructed of large diameter cuttings with the basal (butt) ends of the cuttings placed well (50 cm to 80 cm) into the groundwater table adjacent to the newly constructed watercourse (Figures 6.24 and 6.25). The length of the cuttings depends on the channel to be spanned. However, where cuttings are greater than about 5 m long, the flexibility of the cutting becomes a problem. Overlapping the basal ends of the cuttings allows a dense lattice of willow to be constructed.

Prescription Indicators for Live Shade:

- Where newly constructed fish channels lack riparian vegetation.
- Where clearing close to natural water courses has removed riparian vegetation.
- To reduce water temperatures on tributary, non-fish bearing streams in cut blocks where cover has been removed.

Suggested Construction Tips for Live Shade:

- Large diameter cuttings provide greater strength and are less flexible than smaller diameter cuttings.
- The basal end of the cuttings must be inserted well into the water table next to the stream to avoid desiccation of the cuttings.
- The tripod should be lashedwith a material that will last at least two years to allow sufficient growth to support the structure once the lashing deteriorates.
- In areas with abundant winter snow, the angle of the tripod legs must be no more than 45° from the vertical. Steeper angles will provide greater strength.
- Overlapping the legs of several tripods can provide zones of continuous shade.

Cost Factors: The following factors will tend to increase the cost of live shade.

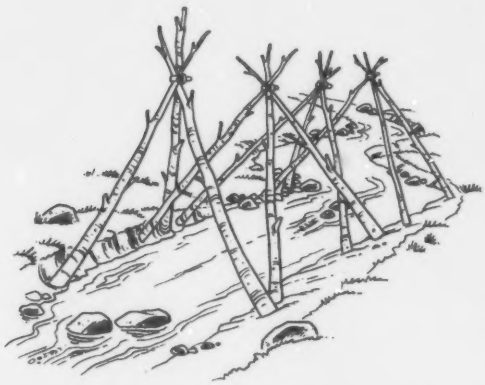


Fig. 6.24 Live shade is used to provide overhanging riparian vegetation on newly constructed fish habitat. The structures send up numerous new shoots while the butt ends of the cuttings root in the moist soils on the banks. The basal ends of the cuttings used in live shade construction should be inserted well into the banks of the new channel. The key to avoiding a severe root to shoot imbalance is to ensure that the basal ends are within the groundwater zone. The tips should be tied together with binder twine or zip straps. The legs of the tripod forming the live shade should be adjusted so that the angle from the vertical is at least 45°. Overlapping the basal ends of a series of tripods can increase the amount of cover afforded. A dense latticework of living willows will provide more complete canopy closure than an open structure.

Fig. 6.25 Live shade installations after flushing of cuttings.

- Access to the site.
- Nature of the substrate adjacent to the channel. Costs will be less where the substrate is easy to dig.
- Availability of suitable long, strong riparian cuttings near the work site.
- Need to respect fisheries windows.

Additional Comments:

- Live shade can be a cost-effective means of providing immediate riparian cover in areas of newly-constructed fish habitat.
- Live shade can be used within cut blocks to help regulate the water temperature of small tributary streams until the second growth is of sufficient size.
- Where beavers are present, some protection, such as chicken wire, may be needed on the legs of the tripod.

6.4 Site Factors, Species and Installation

Soil bioengineering has been used successfully in every biogeoclimatic zone in British Columbia except the Alpine Tundra Zone. It is particularly effective where the species (willow, cottonwood and red-osier dogwood) used for construction are naturally abundant. The species used in soil bioengineering are pioneers and are especially well adapted to establishing on harsh, recently disturbed sites. As pioneering plants, the species used in soil bioengineering prepare the sites for invasion by later successional species. The stabilization created by the soil bioengineering encourages invasion and colonization by species such as alder and pioneering conifers.

The key to successful soil bioengineering projects is to treat the plant materials that are used in construction as living plants. This requires keeping the cuttings moist, avoiding physical damage where possible and using them as soon as possible after collection. Some installations may require irrigation during the first growing season.

Most soil bioengineering projects are conducted during the dormant period of the plants used. At this time the plant materials have the greatest amount of stored carbohydrates (energy reserves) and are physiologically prepared for new growth. For some soil bioengineering techniques, where most of the cuttings are quickly placed in moist soil such as in live pole drains, modified brush layers and brush layers, installation can be conducted in the late summer before the dormant period. In these cases, the cuttings may actually start to grow before winter.

Most woody plants go through cycles of root and shoot growth. As the major obstacle in the establishment of cuttings is to balance the shoot growth with sufficient supporting roots, cuttings should not be used when the shoots are actively growing. An exception is where the placed cuttings will extend well below the groundwater table and moisture stress can be avoided. Collection and use of plant materials during the dormant season is recommended to avoid problems associated with the use of physiologically inappropriate plant materials.

Willows are the primary plants used in soil bioengineering, although cottonwood/balsam poplar (*Populus balsamifera ssp. trichocarpa* and *ssp. balsamifera*) and red-osier dogwood (*Cornus stolonifera*) can also be included. There are a large number of willow species in British Columbia and many are suitable for soil bioengineering. The two most commonly used species are Scouler's willow (*Salix scouleriana*) and Pacific willow (*Salix lucida*). However, most willows will work well and species such as Bebb's willow (*Salix bebbiana*), pussy willow (Salix discolor), glaucous willow (*Salix glauca*) and Sitka willow (*Salix sitchensis*) that are commonly found throughout British Columbia are widely used. The key in selecting appropriate species for use on a soil bioengineering project is to use willows that occur naturally in the project area. Upland species would not be the most appropriate for riparian installations, while riparian species would be less suited for upper slope restoration.

Soil stabilizing plants need proper growing conditions. While the species used for soil bioengineering will grow under extreme conditions, the probability of success is increased by paying attention to small details during construction. All plants need fine textured soils for optimum moisture and nutrient exchange. For structures such as wattle fences and live gully breaks that comprise a face of cuttings, the soil must be tightly pressed against the backs of the cuttings to ensure growth. Inadequate backfilling is the single biggest cause of failure of establishment. Backfilling with coarse rocky material may also lead to failure. Where the soil bioengineering system has a distinct top and bottom, such as on modified brush layers, brush

layers and live staking, the cuttings should be placed in the correct orientation (i.e. with the top or distal end up and the bottom or proximal end down into the substrate).

Although soil bioengineering work should ideally be conducted when the plant materials are dormant, where this is not possible, provisions should be made to keep the plant materials and young plants moist. Consideration should also be given to ensuring that the plant materials have sufficient stored energy (carbohydrate) reserves to sprout, roots and grow. Typically, plants go through a low energy period for about six weeks around the time of full leaf expansion as all energy reserves have been expended in the growth of new roots, shoots and leaves. The hormonal balance in the plant should also be considered. Plants that are in the process of growing new shoots (buds are bursting) will not be hormonally prepared for root growth. Severe root to shoot imbalances can occur when such plants are used for soil bioengineering. There may be opportunities to collect plant materials during the dormant period, store them in a refrigerated van or snow bank and then use them later in the season when the natural vegetation has flushed. Similarly, soil bioengineering sites can be prepared during the summer and the living plant materials added later at the appropriate times. Techniques such as modified brush layers can be largely constructed with the cuttings added later. In areas of abundant moisture, early fall work before the dormant period can be effective. Care must be taken to remove all leaves from the plant materials and to ensure that most of the cuttings are adequately buried. **In all cases, it is important to keep in mind that living plant materials are being used that must be kept alive.**

Cuttings that are used for soil bioengineering need to contain enough moisture and nutrients to allow growth. A good "Rule of Thumb" for the diameter of cuttings is that the narrowest part of the cutting should be at least as big as your thumb. That is to say, cuttings should be at least 2 cm in diameter at the tip. Cuttings up to about 10 cm in diameter can be used effectively in soil bioengineering work. In all cases the cuttings should be healthy and free from insect pests and disease. Cuttings that are used for structures such as wattle fences, live pole drains and live bank protection should be as long as possible since longer cuttings will sprout more readily than short cuttings. For use as live stakes and in structures such as live silt fences, modified brush layers and live gully breaks the cuttings must be at least 40 cm long. Where sites are dry, longer cuttings may be necessary. The key to successful growth of the planted material is to use cuttings large enough and buried deeply enough to ensure that they do not dry out during the driest period of the summer. This may require cuttings that are much larger than the minimum dimensions noted above.

Cuttings to be used in soil bioengineering projects require special considerations and care. The living tissues of the cuttings must be kept moist and protected from physical damage. In some cases, scheduling of soil bioengineering projects requires that the live cuttings be stored for a period of time prior to their installation. **The key to successful storage of cuttings is to ensure that the viability of the plant tissue is preserved**. Cuttings can be successfully stored at about 2^{o} to 3^{o} C in a moist environment for up to 3 to 4 months. During this time, however, carbohydrate levels in the plant material drop as the plant cells respire. For this reason, a stored cutting will have less energy for growth compared to a freshly collected cutting. Cuttings can be stored for shorter periods of time immersed in water, buried under snow, or in commercial coolers. There is some evidence that rooting is enhanced in cuttings that have been soaked in water for about two weeks prior to installation. For more information, visit the web site www.ars.usda.gov/is/pr/2000/000927.htm.

Collection of plant materials for use in restoration projects should be done in a manner that will not impact the plant population. Similarly, plant materials should not be collected from private property without the permission of the owner. Where extensive collections of plant materials are made on Crown land, it is recommended that the Ministry of Forests' district office be informed although there are currently no restrictions on the collection and use of willows for soil bioengineering projects. Similarly, consultation with the Ministry of Environment Lands and Parks will help to ensure that cuttings are not collected in parks or in important wildlife areas or in riparian areas where damage to fish habitat might occur.

6.5 Operational Tips

Planning is the key to successful soil bioengineering projects. Detailed assessments (see Section 6.2) and prescriptions are essential to proper project planning. Knowledge of the type of structures to be used as well as the numbers of structures that will be needed is required for accurate planning. Access and site safety are prime considerations in soil bioengineering projects as most of the work involves hand labour. The following tips are provided to aid in successful implementation of soil bioengineering projects:

- Detailed assessment of the site to be treated is used to plan the treatment program. From the assessment and prescriptions a detailed list of required materials and tools is compiled.
- Where a large number of sites, or where a single large site will be treated, plan the collection of the living plant materials to minimize the time between collection and use. Scheduling part of the crew to collect the plant materials and the remainder to install the structures may help to accomplish this. Condition of the cuttings is critical and storing them in water temporarily will assist in maintaining healthy cuttings. This is particularly important where the cuttings have been stored and where loss of moisture may be a problem.
- Unforeseen conditions may require treatment modification. Any proposed changes should be reviewed by the person who developed the original prescription for the work, or by someone suitably experienced in soil bioengineering. In some cases, it is difficult to determine the exact nature of site conditions during the assessment phase of the project and prescriptions developed from the assessment may need to be altered on the basis of field conditions prevailing at the time the work is undertaken.
- Transport of materials and tools must be undertaken with consideration for the accessibility of the work site. It may be more cost-effective to have a helicopter deliver the necessary tools and materials to a work site if crew access is by foot.
- Use of t trained workers increases productivity and improves workmanship. Where available crews have little or no experience in soil bioengineering, providing on-site training during the first few days of project implementation will help to ensure structures are installed safely and in the correct locations and manner. Supervision by qualified persons will help to minimize problems and increase the probability of success.

6.6 Costs

Costs for soil bioengineering projects can vary substantially due to site conditions and logistics. The costs summarized in Figure 6.26 have been derived from more than 20 years of soil bioengineering projects throughout British Columbia. Although the cost of labour and materials has risen over this period, the improved efficiency of the crews and the development of new

installation techniques have kept costs reasonably constant. There are now a substantial number of contractors available in British Columbia who can complete soil bioengineering projects in a timely and effective manner.

Soil bioengineering project costs include material, delivery and labour. Material costs are relatively fixed for items such as rebar, boards, fasteners, etc. Cost for cuttings, however, can vary significantly depending on source location, ease of collection and storage requirements. Delivery costs depend on project location, the source of cuttings, and any special transport requirements (e.g. refrigeration). Labour costs can be calculated on the basis of standard wage rates at the time of the project. The figures provided in Figure 6.26 assume average conditions for most soil bioengineering projects and are based on current year 2000 costs and labour rates for fully installed bioengineering structures (all-found costs).

Fig. 6.26 Soil Bioengineering Costs

Technique	Range of Costs	Area Treated	Cost/Unit Area
Wattle Fences	$15 - $35/LM	2 m2	$7.50 - $17.50/m2
Modified Brush Layers	$40 - $70 each	10 m2	$4 - $7/m2
Brush Layers in a Cut	$40 - $60/LM	2 m2	$20 - $30/m2
Brush Layers in a Fill	$20 - $35/LM	2 - 5 m2	$7 - $10/m2
Live Reinforced Earth Walls	$25 - $100/LM	4 - 10 m2	$6 - 10/m2
Live Pole Drains	$20 - $60/LM	variable	variable
Live Silt Fences	$20 - $40 each	variable	variable
Live Bank Protection	$15 - $30/LM	1 LM	$15 - $30/LM
Live Gully Breaks	$25 - $60 each	5 - 10 LM	$5 - $6/LM
Live Staking	$1 - $4 each	1 m2	$1 - $4/m2
Live Gravel Bar Staking	$1.50 each	2 m2	$0.75/m2

LM = Linear Metre

7.0 Detailed Assessment and Prescription Reports

7.1 Introduction

The type and content of detailed field assessment and prescription development reports may vary considerably. For small projects where there is considerable existing data, or where the prescription is specific to a limited number of sites, reporting may contain only the site objectives and the information necessary to implement the work. For more complex projects, such as road deactivation prescriptions for unstable terrain, reporting may include detailed observations and assessment of terrain stability. This section suggests a report format covering a number of report considerations, including:

- Description of restoration objectives (watershed to site level) and treatment activities;
- Background information on the project area including reference to previous studies;
- Prescription methodology (field);
- Site level information;
- Results and recommendations;
- Site plans and illustrations; and
- The need for sign off by qualified registered professionals, Licensee representatives or the District Manager

7.2 Suggested Report Framework

Description of Restoration Objectives

A clear statement of restoration objectives at the site level is important to focus the implementation of prescriptions and to determine the effectiveness of treatments later. This may include a description of resource values at risk in the project area and the rationale for the activities proposed to reduce these risks. As well, prescriptions will be influenced by the level(s) of access desired following restoration.

Background Information

For all projects, information on project location and access is necessary for implementation planning. Additional knowledge of the physiographic, climatic and geological/geomorphological setting may be useful if it cannot be referenced elsewhere. Pertinent recommendations from previous studies may also be valuable.

Prescription Methodology

Details provided in the prescription methodology may indicate whether or not field changes during implementation might be expected. These include:

- qualifications of the personnel involved;
- field conditions encountered during the work; and
- factors that may have limited the fieldwork.

Site Level Information

Detailed site level information can alert supervisors and operators to safety or environmental concerns, access considerations, and other site factors that may influence implementation costs, etc.

Results and Recommendations

An effective report might include:

- determination of whether the hazards can be reasonably mitigated by the restoration work and the expected level of residual risk following the work;
- delineation of sites requiring special considerations (especially those with high risk and/or requiring review by specialist);
- cost effectiveness;
- preparation of workplans in sufficient detail to be understood by persons reviewing the plans and by equipment operators and field crews.
- required approvals and personnel for environmental monitoring;
- recommended qualifications of site supervisor;
- recommended inspection schedule following works; and
- recommended level and intensity of effectiveness evaluation, including sites that may be appropriate for detailed evaluation.

Cost-estimates for project implementation and descriptions of necessary resources (personnel, equipment, materials required) may be required.

Tables, Plans and Illustrations

Items in the report describing the work should include:

- 1:5,000 scale (or other suitable scale) maps with topographic base;
- prescription tables listing the locations and description of works, as well as any site specific information collected;
- detailed site diagrams for special sites; and
- site photographs (taken from established photo stations if recommended as evaluation sites) where appropriate.

8.0 Implementation of Major Works

8.1 Introduction

Road deactivation and hillslope rehabilitation projects (termed "works" in this section) require significant planning as well as appropriate site supervision and inspections. This section discusses implementation of work once the prescriptions and treatments are developed and approved. Also presented are guidelines for pre-work planning, project scheduling, environmental and safety monitoring, as well as suggestions for inspecting completed work, reporting, and professional review.

8.2 Pre-Work Planning

Pre-work planning pulls together the "loose ends" of the project before equipment is moved to the site. For road deactivation works, a reactivation plan and prescription requirements will contain many of the essential elements for pre-work planning (See Section 3.4).

Pre-work planning may involve:

- Obtaining/confirming the necessary approvals from government agencies with jurisdiction over the planned activities (forests, fisheries, environment, mines);
- Reviewing sites that present safety concerns, and deciding if the available personnel can complete the deactivation work safely (or possibly identifying areas where more experienced operators are needed);
- Scheduling of equipment/activities to meet timing windows or other specific timing considerations for the work (such as seed windows for revegetation or access constraints);
- Reviewing work requirements and matching available equipment to required tasks to ensure that the work will be completed safely, effectively, and productively;
- Estimating materials needed on site (such as culverts, grass seed, and sediment control supplies);
- Deciding on the appropriate level of quality assurance needed for site supervision to coordinate deactivation work and revegetation, environmental monitoring at appropriate crossings/locations, and qualified registered professional inspections and reviews where appropriate.
- Coordinating work with ongoing forest operations in nearby areas.

Good pre-work planning anticipates and addresses problems before equipment starts deactivation work. It can also detail the sequence of work, especially with respect to timing windows for environmental monitoring and the availability of machinery and personnel.

On-Site Information Package for Deactivation Crews

Many of the items listed above will provide a basis for an on-site information package for field crews and site supervisors carrying out the work. Other useful information in this pre-work package may include:

- Standard Operating Procedures for the company or licensee relating to safety and environmental considerations;

- Objectives and site specific requirements for implementing sediment control techniques;
- Standard Operating Procedure for suspending operations during intense rainstorms or extremely wet conditions;
- Protocols for field inspections by the qualified registered professional taking responsibility for the completed deactivation work;
- An Emergency Response Plan with area and operation specific information regarding the steps to take in the event of a safety or environmental emergency.

Pre-work meeting. Prior to the start of deactivation or rehabilitation work, a meeting between the field crew, site supervisor, and if necessary, the qualified registered professional may be beneficial. The purpose of the meeting is to review the scope of the deactivation/rehabilitation work as well as site-specific information (prescriptions and pre-work package). Sediment control objectives and techniques can also be reviewed. It is also important to discuss the roles of the site supervisor, environmental monitor, and qualified registered professional on the project and to establish an open working relationship with all members of the deactivation/rehabilitation so problems are solved as they arise.

Before work begins, the field markings should be verified and re-established as necessary. This may involve re-chaining the stations using the Tables in the road deactivation report from a known point (or reference point) in the field. For landslide or gully rehabilitation, this may involve zoning of the rehabilitation area and re-establishing reference points.

It may be beneficial to have the qualified registered professional on site prior to the start of work, particularly in cases where the success of the deactivation depends on unknown subsurface conditions, or where unusual or complicated geotechnical/geological conditions exist that will affect the success of the work.

8.3 Work Scheduling

The type of the work and the potential safety or environmental risk determines the scheduling of any road deactivation and hillslope rehabilitation undertaking. Proper scheduling also sequences the availability of suitable equipment or experienced personnel to successfully complete the work. For example, the conditions for scheduling deactivation of large road fills on steep slopes may involve special considerations such as the availability of qualified operators (with proven experience in ramping and benching) and suitable equipment; scheduling the work for times of expected drier conditions, and using conservative rainfall shutdown guidelines to reduce exposure to upslope landslide hazards.

Revegetation treatments should be timed to coincide with favourable weather windows (see Sections 3.8, 4.3, 5.3, and 6.4). It may be logistically practical to apply a treatment during a less favourable time period (e.g., seeding of road deactivation typically occurs during the driest period of the year), thus, treatment effectiveness may be limited and further work may be necessary.

Fisheries habitat in the work area may affect the scheduling. During fisheries windows when the risks to important commercial, sport, and resident fish are reduced, some limited work in and around a stream may be possible. Consultation with fisheries specialists can help ascertain potential impacts to specific species present in the drainage. At locations where fish are present, fish salvage may be required.

Various federal and provincial legislation statutes may apply where deactivation or rehabilitation work could cause some level of soil disturbance that may pose a risk to aquatic resources, such as fish habitat or water quality in community watersheds. Practitioners are responsible for ensuring that the planning and implementation of the work meet all regulatory and legislative standards.

8.4 Safety

A Health and Safety Plan is recommended for all field activities from assessment to implementation. All field personnel should be familiar with potential safety hazards associated with carrying out a specific task at a particular work site. For work in remote locations, GPS tagged helicopter pads can help to minimize response time during emergencies.

Potential hazards at hillslope work sites may include landslides (debris slides, debris flows, rockslides), and rockfalls. Snow avalanches and windthrow (danger trees) may also present a hazard. Intense rainstorms, windstorms, and rain-on-snow events increase the likelihood of road fill landslides and suspending operations may be prudent. Monitoring rainfall at the worksite is important and suspending operations when thresholds are reached can decrease the hazard exposure. Rainfall shutdown criteria provided for the specific area of work should be determined and followed.

Where landslide or gully rehabilitation activities are carried out on steep or unstable slopes (e.g., seeding, planting, soil bioengineering) standard operating procedures can be used to increase the safety of workers on these slopes. In many cases, the hazard associated with slippery basal tills and rockfalls can increase with intense rainstorms. Frost and wind action on root wads can pry rocks loose. In these cases, activities in safer areas (such as collecting cuttings or organizing materials) can often be carried out when work on the slopes is unsafe.

Safety is the responsibility of everyone involved in the project. While planning and assessment may identify some potential safety hazards at a work site, other hazards may not present themselves until the work is carried out. If a safe approach is not evident for a particular task, site supervisors or qualified registered professionals should be consulted.

Note that Workers' Compensation Board regulations apply to all work, especially work below unstable slopes, danger trees, and blasting areas. Many companies and licensees also have standard operating procedures for safety that must be followed. Practitioners are responsible for ensuring the work is planned and carried out in a safe manner and that all appropriate regulations and standard operating procedures are observed.

8.5 Environmental Monitoring

The objectives of environmental monitoring are:

- To ensure that the work is carried out in compliance with applicable regulations and legislation;
- To assist in minimizing the impacts of the deactivation work on the aquatic environment;
- To provide due diligence for deactivation work near aquatic habitat.

Environmental monitoring may not be necessary for some activities carried out under the Forest Practices Code or within times indicated by fisheries windows for specific operating areas. In

these cases, field crews carry out monitoring on a daily basis and a designated environmental monitor may not be needed.

When required, environmental monitoring includes on-site inspections to:

- Evaluate the effectiveness of sediment control measures and specific techniques;
- Observe site conditions and record activities;
- Carry out any necessary fish salvage;
- Promote environmental awareness to deactivation crews; and
- Liaise with regulatory agencies.

***Fig. 8.01** Fish salvage is necessary when conducting work in and about fish streams.*

8.6 Site Supervision and Inspections

Site supervision and on-going inspections verify the quality of the work carried out and solve problems as they arise.

Site supervisors must have an understanding of how to implement the prescriptions in a cost-effective manner, given the crew expertise and equipment available. On a road deactivation project, for instance, the site supervisor must understand:

- The overall project objectives for the deactivation work and the objectives of the specific techniques in the prescriptions;
- The techniques applied to specific sites, and how they can be completed cost-effectively;
- The extent to which the techniques can be modified to adjust for local conditions (such as reducing the amount of coarse rock required for erosion protection, where such rock is not readily available).
- The capability of the equipment and the experience of the crews to deal with the work;
- The need for inspections by others (environmental monitors, qualified registered professionals) at appropriate sites.

For road deactivation, the extent of site supervision will depend on the number of machines on site, the experience of the operators, the complexity of the road and hillslope stability conditions, the difficulty of the deactivation work to be carried out, and the number of safety hazards along the road. Where an experienced operator is carrying out straightforward deactivation, only intermittent site supervision may be warranted. However, full time supervision may be required in cases where less experienced operators are working, or more complicated prescriptions are being implemented. The amount of supervision should also be discussed with the qualified registered professional. Usually, increased supervision is less expensive than correcting mistakes later, and much less expensive than reconstructing access through heavy pullback areas.

Inspections are commonly carried out to establish the quality of the completed deactivation work and provide feedback to site personnel. When reviewing the completed deactivation work, it is important to determine if the objectives have been met.

During monitoring and inspections, it is important to discuss the completed work with operators. Questions that can be useful in evaluating the completed work include:

- Were there any discrepancies between the prescriptions and ground conditions? (Did prescriptions make sense based on the ground conditions, have the ground conditions changed significantly since prescriptions were completed?)
- Does the operator expect problems in completing the prescriptions ahead?
- Is there anything ambiguous in the prescriptions?
- Are there places where the prescriptions could not be met and significant residual risk remains?

The effectiveness of sediment control techniques at specific sites should also be checked to determine if improvements are possible.

During inspections, it is important to walk the deactivated road and make direct observations. For pullback areas, walk both the top of the pullback and the lower edge of the pullback. The table in Figure 8.02 lists a number of site indicators that can be evaluated for some types of deactivation work.

Fig. 8.02 Example observations related to the inspection of deactivation work

Road Fill Pullback	
General	• Do operator and site supervisor know machine location in relation to both reactivation and deactivation prescriptions?
Prescriptions	• Do the limits and extent of the road fill match the prescriptions? Was more or less pullback needed than prescribed?
Full Road Fill Pullback	• Does fill remain supported at toe? • Is this material stable? What is the residual hazard and risk? • Has adequate level of access been maintained where specified?
Road Fill Placement	• Is the material placed tight to the road cut? If not, what is residual hazard? • Are hollows and depressions evident on pullback surface, to mimic topography above and below the road? • Is recontoured slope straight, concave, convex in profile? What is residual hazard? • Is all woody debris randomly on top of the pullback material? Woody debris should be oriented for reduction of surface erosion. Random placement helps to intercept surface flow before rilling and erosion develop. This is especially important in fine-textured soils. • What is the composition of material on recontoured slope? (The composition of the pullback material on the slope compared to the road cut can provide information on how the pullback was carried out).

Water Management	
General	• If sediment control measure were installed, have they been removed?
Prescribed actions	• Can the prescribed techniques (cross-ditches, etc) be located in the field? Are they functioning as intended?
Cross-ditches	• Does cross-ditch restore natural drainage path? How does its width compare to the natural channel above and below the road? • Does the profile of the cross-ditch mimic the natural ground profile, (in pullback areas)? • Has sufficient road fill been retrieved at outlet? • If necessary, is armour present, properly located, and of adequate size, given anticipated flows? A general rule is to mimic armour composition and size located in the channel or depression above and below the cross-ditch location. • Will armour placed in the channel impede or divert flows? What is residual hazard? • Are fillslopes adjacent to location adequately resloped? • Are the sides of the cross-ditch appropriately sloped? • Is base V-notched or U shaped? Is slumping expected from adjacent road fill into the cross-ditch? • Is the cross-ditch grade steep enough? Will water flow across or pool? • Do cross-ditches allow required level of access?
Blanket Drains	• Is water evident at the toe of the blanket drain?

These site observations are examples only and not intended as a complete list. Inspections should always concentrate on whether the site objectives were met by the work carried out.

Information from inspections should be compiled in a summary of completed deactivation work. The qualified registered professional may review this summary as part of a quality assurance review of the completed work. This summary can be a valuable complement to a site review to determine suitable sites for effectiveness evaluation.

8.7 *Example Protocol for Professional Field Reviews*

The table in Figure 8.03 is an example of a protocol that was used on road deactivation projects for coastal areas. The professional involved had worked previously on several projects with both the senior site staff as well as some of the operators. The objective in developing the protocol was to set out guidelines for consultation with the qualified registered professional responsible for the work, yet allow site supervisors to make some minor changes without consultation. Use of a protocol such as this is at the discretion of the qualified registered professional.

No consultation with qualified registered professional required; add changes to as-built documents	♦ Changing a cross-ditch to a blanket drain or trench drain in heavy pullback (outside stream areas) ♦ Adding or changing locations or cross-ditches to suit site conditions in areas with less than 50% slopes below the road and with no evidence of landslides ♦ Adding or eliminating non-stability related items such as heli-pad locations, etc. (that do not affect the amount of prescribed pullback) ♦ Limited increases to the length or amount of road fill pullback in permanent deactivation where no access is planned following deactivation
Discussion with qualified registered professional required; field review may be needed prior to work	♦ Decreasing the amount of road fill pullback (low consequences) ♦ Varying from the approved work plan (where timing windows are present) ♦ Working outside the fish timing window as outlined in the deactivation prescriptions ♦ Deactivation on low risk roads found on flat slopes that were previously not assessed; may require agency approval ♦ Eliminating cross-ditches without installing any other water control structures (such as blanket drains, trench drains, etc) ♦ Adding or changing the locations of cross-ditches in areas with slopes greater than 50%, or slopes with landslides
Discussion with qualified registered professional; field review of site usually required prior to work	♦ Decreasing the amount of road fill pullback (high consequences) ♦ Changing the level of deactivation as approved on the plan for access management (such as adding an ATV trail in full pullback areas, or eliminating access in areas where access was to be maintained) ♦ Unable to fully implement the prescription due to safety concerns, or excessive large woody debris, etc.; where mechanical work was not feasible or where blasting may be required to remove/reduce residual risk ♦ Roads on steep slopes that were previously not assessed, and will be isolated by deactivation activities ♦ Substantial changes required to prescriptions after the road has been brushed out and/or reactivated.

Fig. 8.03 *Example protocol for making field revisions to approved road deactivation prescriptions.*

All revisions should be fully documented for the work completion reports. Where appropriate, sketches and/or photos should be included to provide the best possible information about the conditions during and immediately after the work.

9.0 Effectiveness Evaluation

9.1 Introduction

Effectiveness evaluation is an essential, but often neglected, component of any restoration activity. It measures to what extent the work performed has attained the watershed restoration objectives. The benefits of effectiveness evaluation include:

- more efficient allocation of funding and optimization in planning/decision-making (i.e. program benefits);
- a measure of the state of recovery of the watershed (i.e. how much restoration has been achieved, how much more effort is required); and
- technical feedback to refine restoration treatment design and implementation.

This section provides a basis for the development of routine evaluations of hillslope activities for watershed restoration. Program development, including determination of appropriate evaluation objectives, study design, selection of evaluation variables, sampling methodology and suggested sampling protocols are discussed. Analysis of sampling data and presentation of results are also described. Although this section deals only with evaluation of hillslope works, any program of effectiveness evaluation should be an integrated effort whenever practical, combining evaluation of completed hillslope, riparian and stream restoration works.

Effectiveness evaluation addresses three fundamental questions with respect to restoration:

1. Is the restoration work achieving the desired objectives?
2. How can techniques be improved?
3. How can the cost-effectiveness of the work be improved?

Effectiveness evaluations for watershed restoration may range from inspections to validation evaluations (i.e. research) as shown in Figure 9.01.

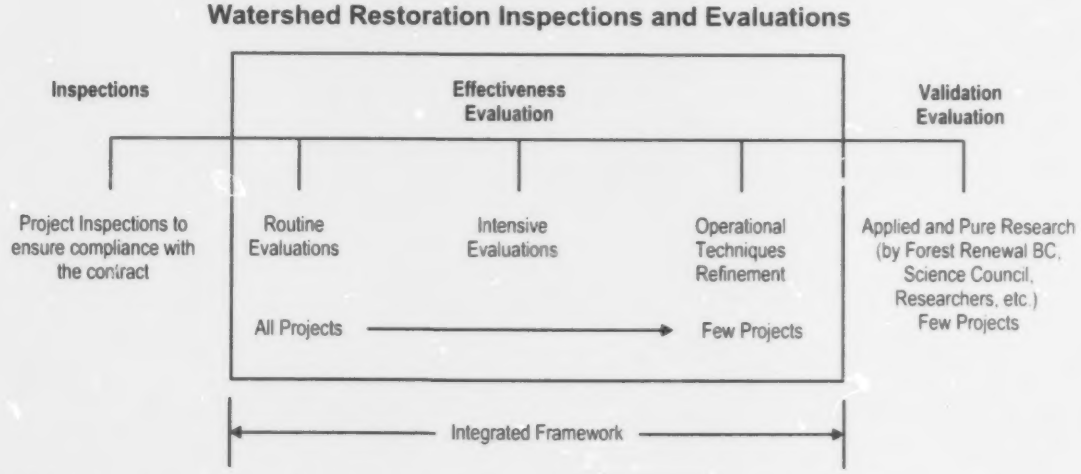


Fig. 9.01 Inspections and evaluations that may be associated with watershed restoration.

Any watershed or sub-basin can be segregated into its hillslope, riparian and stream components (Figure 9.02). For the hillslope component, sub-components may include roads, landslides and gullies. Further division to the site level may include features such as cutslopes, fillslopes and cross-ditches for roads, headscarp, transport and deposition zones for landslides, and headwall, sidewall, channel and deposition zones for gullies.

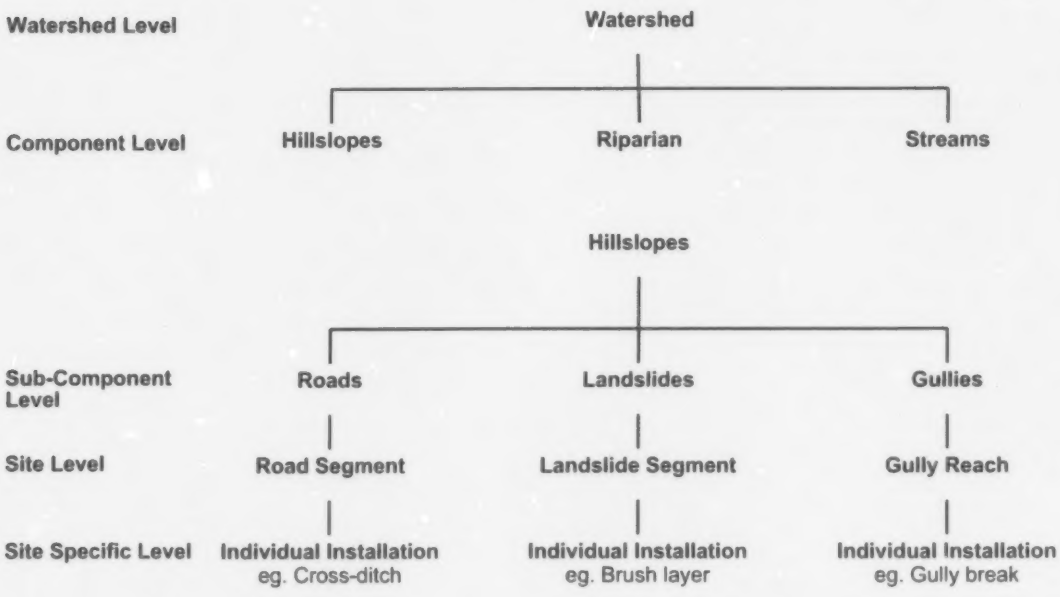


Fig. 9.02 Watershed, Component and Site Levels

The evaluation of effectiveness can be performed at specific levels of intensity with benefits and limitations associated with each level. Measured or observed responses may be dependent upon the effect of a specific activity (e.g., an increase in vegetation cover due to seeding) or the combined effects of a number of activities (e.g., the improvement in water quality due to the cumulative effect of all hillslope treatments).

Three levels of effectiveness evaluation are possible: routine evaluation, intensive evaluation and operational techniques refinement. Routine evaluation is the low cost overview evaluation that will be appropriate for the majority of restoration projects. Intensive evaluation and operational techniques refinement are generally specialized studies chosen for selected sites, and are beyond the scope of this document. See WRP Technical Circular No. 12 by Gaboury and Wong (1999) for further information. A comparison between these three levels of evaluation is shown in Figure 9.03

*Fig. 9.03 Comparison of Effectiveness Evaluation Levels**

Evaluation Levels	Scale	Methods	Personnel	Data Type	Timing/Duration	Data Analysis	Outputs
Routine	Watershed to site level; sample locations confined to specific watershed (all treatments and projects to be evaluated)	Aerial and ground-based surveys; non-specialized study design	Technicians + specialist guidance	Qualitative with ratings and Quantitative with or without ratings; (Physical and/or Biological)	Roads: semi-annually to annually for SP and high risk P deactivation for 5 years or until residual risk is acceptable. Landslides and Gullies: every year for first 2 years then every 5 years (until residual risk is acceptable).	Comparative and graphical analysis (means, bar graphs, etc).	Short summary of functional condition of works, failures, remedial works requirements. General treatment performance. Level of residual risk. Evaluate treatments as to meeting objectives; rate or measure variables. Comparisons made with bio-standards, WRP, FPC, policy standards.
Intensive **	Variable; sample locations may be from several watersheds (few treatments or projects to be selected for studies)	Detailed ground sampling using mainly existing protocols; requires specialized study design	Specialists	Quantitative mainly; intensive measurements; Physical and/or Biological	Site specific but generally long term. Variable sampling frequency.	Statistical study design.	Routine Outputs plus: Statistically derived inferences; identification and comparison of relationships between variables; process relationships.
Operational Techniques Refinement **	Variable; sample locations may be from several watersheds (few treatments or projects selected for studies).	Detailed ground; sampling protocols may be existing or require development; requires specialized study design	Specialists, service reps	Quantitative; Physical and/or Biological	May be one time only, dependent on evaluation objectives.	Statistical analysis is driven by study.	Main output is cost-benefit and decision analysis.

* Details provided are general characteristics, specific projects may vary.
** Recommend that these levels of study be proposal-driven.

Routine effectiveness evaluation can be conducted by qualified technicians with specialists providing minimal guidance in study design and sampling protocol. In general, all WRP projects should be routinely evaluated for a minimum of one year after completion of the work. Routine evaluation may continue on all or a portion of the project area depending upon assessment of residual risk, and on the benefit of evaluating specific sites to provide longer term information. As a general guideline, budgeting for routine monitoring should be approximately 4 % of the cost of the physical restoration works.

The main objectives of routine evaluations are to:

- assess the present configuration and condition of restoration treatments (i.e., are the works still in place);
- qualitatively and/or quantitatively assess whether or not the treatments have been effective in addressing the restoration objectives (i.e. are the works functioning as intended, how well are they functioning);
- determine if remedial work is needed; and
- identify specific hillslope areas which may warrant a more rigorous evaluation or a more specific investigation.

9.2 *Routine Evaluation*

9.2.1 Evaluation Objectives

Restoration objectives are developed during the initial overview assessment and restoration planning process. Project objectives may initially encompass the broad watershed level, but are further refined at the component and site levels. Watershed, component, and site-level restoration objectives provide the basis for all restoration work conducted within a watershed. Appropriate restoration objectives are specific, obtainable, measurable and represent some desired future condition. They may represent previously established standards or guidelines, or they may represent benchmark conditions from unlogged watersheds. Restoration activities are the physical works conducted to meet restoration objectives. For hillslopes, the main activities typically include road deactivation, landslide rehabilitation and gully rehabilitation. Effectiveness evaluation objectives are intended to determine if the restoration objectives have been met at the appropriate corresponding levels. In Figure 9.04, a hierarchical sequence of restoration objectives and corresponding effectiveness evaluation objectives is shown. Grouping of effectiveness for each site level objective provides a means of determining if sub-component and component level restoration objectives are being met, and ultimately if watershed objectives are being met.

Fig. 9.04 Restoration Objectives, Restoration Activities and Effectiveness Evaluation Objectives

Level	Restoration Objective	Restoration Activity	Effectiveness Evaluation Objective
Watershed	Reduce the generation of sediment related to logging activities.	Take measures to reduce the incidence of logging-related mass-wasting and rehabilitate existing sites of logging-related sediment generation.	Determine if treatments have mitigated sediment generation related to logging activities.
Component	Stabilize and rehabilitate the hillslope areas affected by logging activities.	Stabilize areas of potential failures, provide erosion control for existing sediment sources.	Determine if works have stabilized all areas with potential for failure, determine if erosion control has been successful.
Sub-Component	Reduce mass-wasting and erosion from: Roads Landslides Gullies	Deactivate and revegetate roads Stabilize and revegetate landslides Rehabilitate gullies by reducing incidence or volume of mass-wasting and revegetating.	Determine if mass-wasting hazard has been reduced and erosion control has been effective on deactivated roads, rehabilitated landslides and gullies.

Evaluation objectives may be addressed in even greater detail by focusing on site specific objectives. In Figure 9.05, possible site level variables that may be appropriate for evaluation are shown.

Fig. 9.05 Restoration Objectives, Restoration Activities and Effectiveness Evaluation Variables

Level	Restoration Objective	Restoration Activity	Effectiveness Evaluation Variable
Site	**Road Sites:**	**Road Sites:**	**Road Sites:**
	Reduce volume of fill supported by woody debris, reduce surcharging of slope by fill.	Pullback fillslopes.	Degree of slumping, sliding or other slope instability indicators on fillslope.
	Reduce raveling to allow for establishment of vegetation.	Pullback and reduce angle of fillslope, or install modified brush layers.	% establishment of vegetation
	Provide toe support for unstable cutslopes.	Buttress unstable cutslopes	Degree of slumping, sliding or other slope instability indicators on cutslope.
	Reduce oversteepening of cutslopes.	Reslope cutslope.	Degree of slumping, sliding or other slope instability indicators on cutslopes.

Level	Restoration Objective	Restoration Activity	Effectiveness Evaluation Variable
Site	**Road Sites:**	**Road Sites:**	**Road Sites:**
	Reduce pore water pressure in road fills and native soils by dispersing flow or discharging into established channels.	Install appropriate water management structures at required locations.	Proportion of water management structures functioning at various efficiencies (nominal ranking of efficiency from 1 to 5).
	Reduce erosive capacity of water.	Install water management structures to direct water into non-erodible channels.	Proportion of water management structures functioning at various efficiencies (nominal ranking of efficiency from 1 to 5).
	Increase protection from rain splash, increase interception, reduce surface runoff velocity.	Seeding + plant; apply erosion control blankets, rip rap, mulch; increase slope roughness.	% vegetation cover established, degree of invasion by native species (i.e. have native species established in treated area), degree of rilling (ordinal scale).
	Provide site conditions conducive to establishment of commercial tree species (i.e. reduce soil compaction, increase soil nutrients, provide favourable microsites).	Scarify soil, replace organic soil, create mounds.	% survival and growth rate of commercial tree species.
Site	**Landslide Sites:**	**Landslide Sites:**	**Landslide Sites:**
	Reduce oversteepening of headscarp/sidescarps.	Reslope headscarps/sidescarps to mechanically stable angle.	Extent of headscarp/sidescarp retrogression.
	Reduce pore water pressure in headscarp area.	Divert upslope water away from headscarp area.	Reduction in seepage from headscarp.
	Reduce erosive capacity of surface water in channels.	Install armour, check dams, or soil bioengineering structures along surface channels.	Surface flow confined to intended channels; durability of installed structures (ordinal scale).
	Increase protection from rain splash, increase interception, reduce surface runoff velocity by establishing adequate vegetative cover.	Seeding + plant + soil bioengineering.	% vegetation cover established, degree of invasion by native species (i.e. have native species established in treated area), degree of rilling (ordinal scale).
	Increase soil strength provided by woody species (buttressing, arching, anchoring).	Planting with woody species, installing soil bioengineering structures (wattle fences, brush layers, live smiles, etc).	% survival and growth rate of woody species, survival of soil bioengineering structures and establishment of cuttings.
	Reduce volume of potential debris flow.	Clean logging introduced woody debris.	Volume of subsequent debris flows reduced (as compared to natural events nearby).

Level	Restoration Objective	Restoration Activity	Effectiveness Evaluation Variable
Site	**Gully Sites:**	**Gully Sites:**	**Gully Sites**
	Reduce erosion or likelihood of debris flow/flood initiation from channel.	Remove channel obstructions (i.e. road fill from gully crossings, logging-related woody debris jams, failsafe road crossings).	Amount of sediment transport, frequency of debris flow/flood events.
	Increase soil strength provided by woody species on sidewalls and headwalls.	Plant woody species.	% survival and growth rate of woody species.
	Reduce transport of debris flow/flood material to downstream values.	Construct mitigation structures (berms or basins).	Structure has functioned as intended following event (i.e. debris contained or deflected).
	Increase protection from rain splash, increase interception, reduce surface runoff velocity on denuded sidewalls/headwalls by establishing adequate vegetative cover.	Seeding + plant + soil bioengineering.	% vegetation cover etablished on headwalls and sidewalls, degree of invasion by native species (i.e. have native species established in treated area).
	Reduce potential for avulsion and subsequent erosion on fans.	Excavate channels on fan to increase channel incision, planting, soil bioengineering or riprap to stabilize streambanks.	Frequency of channel avulsion.

Planning for effectiveness evaluation should begin as early as possible in a restoration project since the collection of pre-restoration data may provide useful benchmarks for comparison. Ideally, the collection of baseline data should be incorporated into both the overview/inventory and assessment/prescription phases of work where necessary. A list of possible evaluation variables or parameters should be compiled, the distribution of sample sites considered and limitations (e.g. technical and logistical) identified. Site level evaluation objectives have the most direct linkage to restoration activities and generally require detailed information that is typically obtained during the prescription stage. This may include field verification of the suitability of prospective evaluation sites and evaluation variables. Selection and establishment of photo stations, for instance, might be appropriate at the overview stage and the prescription stage, respectively. To meet budgetary and logistical constraints, the number of evaluated sites may have to be reduced through a screening or stratification process. For completed watershed restoration projects where no evaluation sites were selected, some field verification should be included as a component of the study design. It may be possible to gather some pre-restoration data through review of historical information, such as a compilation of landslide history in a watershed based on review of historical aerial photographs.

9.2.2 Study Design

Evaluation study design will reflect the individual restoration project's set of unique characteristics and objectives. Field verified site level evaluation objectives, as shown in Figure 9.05, will be the major guide for study design.

For hillslope activities, routine evaluation at the lowest intensity may consist of a visual qualitative assessment conducted on all restoration structures and treatments carried out in the project area. This assessment could be carried out either from an aircraft or from review of low level aerial photographs or video. Qualitative assessments use indices of response rather than more expensive and time-consuming direct measures. For example, an indication of road surface erosion might be represented by an estimate of the degree of surface rutting rather than by detailed measures of sediment generation. Establishment of fixed photo points or a detailed video record can be a cost-effective means of demonstrating the change in site conditions over time. At the highest intensity, routine evaluation may be predominantly a quantitative assessment conducted at selected sites within the project area. Measurement of key variables might be carried out on the ground following set protocols. For example, vegetation cover on a landslide or deactivated road could be quantitatively assessed by establishing random vegetation plots. For most studies, some combination of low intensity qualitative and higher intensity quantitative evaluation will be appropriate. Higher intensity evaluations may be warranted for sites where there was a high initial risk, where innovative treatments were applied, or where prescribed work could not be completed (e.g. due to safety concerns, logistical limitations, etc.) or was not attempted (e.g. site was risk managed).

9.2.3 Selection of Evaluation Variables

The evaluation variables selected for a routine level of evaluation should be practical (i.e. obtainable and measurable), yet adequately address the site level evaluation objectives. Some guiding principles for variable selection as described by MacDonald et al. (1991) are:

- The selection of evaluation variables will differ from watershed to watershed as objectives and site characteristics vary;
- Select variables that are the best indicators of change and measure them in the appropriate areas that are the most responsive to change;
- Select variables that provide the best evidence/inference that objectives are being met and are least influenced by extraneous events (i.e. natural variability);
- Select variables that are easily observed, measured and qualified and/or quantified to help ensure consistent data collection; and
- Select variables that are the least influenced by location of sampling or time of sampling.

For watershed restoration, four types of evaluation variable can be defined based on initial conditions and the correlation between variable value and the desired direction of change:

Type I Variable - has an initial value prior to the restoration activity and is negatively correlated with the desired direction of change expressed by the restoration objective.

Examples: number of road fill failures on deactivated road or number of debris flows following gully rehabilitation; variable values should decrease following treatment (high initial value, expected lower value after treatment).

Type II Variable - has no initial value prior to the restoration activity and is negatively correlated with the desired direction of change expressed by the restoration objective.

Examples: degree of erosion along constructed cross-ditch or the number of soil bio- engineering structures that have failed; variable values expected to decrease over time.

Type III Variable - has an initial value prior to the restoration activity and is positively correlated with the desired direction of change expressed by the restoration objective.

Examples: vegetation cover on landslide following hydroseeding or annual growth of conifers in riparian zone after alder brushing; variable values should increase after treatment (low initial value, expected higher value after treatment).

Type IV Variable - has no initial value prior to the restoration activity and is positively correlated with the desired direction of change expressed by the restoration objective.

Examples: vegetation cover on pulled back road fillslope after handseeding, or flow through outlet of installed French drain; variable values expected to increase over time.

9.2.4 Sampling Methodology

Sampling methodology is guided by the overall study design and encompasses sampling aspects such as the nature and number of sample sites (i.e. whether they are continuous or discrete sites), the sampling regime (i.e. duration and frequency of sampling) and the sampling protocols (standardized sampling procedures). Some guidance by specialists may be appropriate in developing the sampling methodology.

As stated, routine evaluation may range from review of all treated sites at a relatively low intensity, to review of a selected subset of sites at variable intensity. Some possible methods of subset selection may be:

- based on residual risk following treatment (i.e. subset may be biased toward higher residual risk sites to determine as soon as possible if remedial action is required);
- via a sampling of specific site characteristics such as terrain type, treatment technique, or initial site conditions (this has the potential to provide the greatest amount of beneficial information); or
- through a random sampling of stratified sites to allow for higher intensity sampling at representative sites.

Sampling should be conducted to provide an initial pre-work site characterization if possible, a site characterization immediately post-work, and post-work evaluation at specified intervals. As the frequency and duration of evaluations for any project may be modified based on the results of initial evaluations, there should be a certain amount of

flexibility in planning. For routine evaluation, it may be appropriate to conduct post-work evaluation of high risk sites initially twice in the first year following work, or after extreme weather events. Depending on results, it may be appropriate to decrease evaluation frequency to once a year for subsequent years. Evaluation of sites may continue for approximately five years or until the residual risk is deemed acceptable (e.g. until evaluation variables have reached apparent equilibrium with the environment). For lower risk sites, initial results may indicate a reduced evaluation frequency to once every second year or longer, or to cease evaluations entirely.

For water management structures and slope stability treatments, evaluations during wet periods are generally most appropriate. For vegetation, sampling during peak growth periods should be considered.

A key consideration of sampling methodology is the collection of easily measured, objective, field-based data using repeatable methods that provides consistent data. Development of standardized sampling protocols, rating systems and field data collection forms are important to ensure:

- a reduction in the subjectivity and bias inherent in assessments conducted by different field personnel;
- a standardized valuation of observations and measurements into well-defined categories; and
- that data can be compiled, summarized and compared objectively with results from other projects.

For routine evaluations, qualitative assessments of structures or treatment can be rated using a binary classification (yes/no), an ordinal scale (good, fair, poor), or a numerical scale (1,2,3,4). Rating levels should be established prior to the field evaluation to ensure consistency in the grading of observations and measurements by field personnel. A certain level of training will be required to ensure consistent data collection.

Sampling protocols for effectiveness evaluation of hillslope restoration have not yet been developed for the watershed restoration in B.C. An example of a possible nominal rating system for evaluating the effectiveness of cross-ditches and other water management structures is as follows:

5 - All water confined to intended channel, no significant erosion (functioning as intended)

4 - All water confined to intended channel, minor erosion evident.

3 - All water confined to intended channel but significant downcutting and sidewall erosion.

2 - Some water diverted from intended channel, partial failure of ditchblock or sidewall; possible remedial action required.

1 - Most of water diverted from intended channel or channel obliterated; remedial action required (total failure).

If such structures are also intended to provide vehicle access, each structure could also be rated for accessibility in a similar manner, or by simply using a binary classification (Yes - accessible/No - not accessible).

A possible rating system for evaluation of the effectiveness of road fill pullback may consist of the following effectiveness rating criteria (ordinal scale):

Good - one or less prominent field indicators of instability or erosion; field indicators selected for use as evaluation variables included evidence of displacement, tension cracks, slumping, non-retrieved road fill, slope failure, incision, water flow obstruction, surface erosion.

Fair - two to three prominent field indicators of instability or erosion;

Poor - greater than three prominent field indicators of instability or erosion.

For routine evaluation of a treated landslide, a reassessment of the site following the LRAP procedure may provide adequate qualitative information. For higher intensity sampling vegetation plots or transects could be established to provide quantitative data.

Rating categories for measured values should be based on comparisons with published guidelines or field procedures.

Establishment of photos stations at selected sites following an established protocol, such as provided in the USDA Watershed Restoration Effectiveness Monitoring Protocol (June 1996), may be a cost-effective means of recording changes in conditions over time. Video records can play an equally important role if procedures are carefully documented and linked to GPS stations.

9.2.5 Analysis and Presentation of Data

Some typical outputs from routine evaluations include summaries of:

- the number, type and location of restoration treatments and the intensity of their evaluation;
- the structural condition, stability, establishment growth of the restoration treatments;
- treatments that need remedial measures and what measures are recommended;
- treatments that require more detailed evaluations (routine or intensive);
- recommendations for improvement in treatment design, technique or implementation;
- residual risk; and
- recommendations for future frequency and duration of evaluation.

Data analyses for routine evaluations may include:

- simple graphical displays of effectiveness rating frequencies by structure or treatment type from visual or ground based measurements;
- comparative analyses of how data in treatment areas differ over time;
- tabular inventories of effectiveness ratings for treatments or structures; and
- comparative analysis of key variable data, before and after treatment.

Interpretation of results aids in determining if the stated restoration objectives are being met. Results that are inconclusive, however, suggest that either:

- the evaluation protocol needs to be modified to provide more precise results;
- the evaluation objectives need to be modified;
- the selected evaluation variables did not adequately address the restoration objectives; or
- the evaluation assumptions may not have been valid.

Any such shortcomings should be identified to guide future evaluation.

Efficient collection, compilation and dissemination of data and results in a timely manner is critical for successful completion of future restoration work. This information will have adaptive management benefits to watershed restoration with respect to future treatment design and application.

The reader is referred to the **most recent and current Schedule A** for Effectiveness Evaluation for details and specifications regarding the planning and implementation of effectiveness evaluation projects.

Glossary

Adaptive Management: is a formal process for continually improving (resource) management policies and practices by learning from the outcomes of operational programs. Its most effective form, active adaptive management, is characterized by management programs that are designed to experimentally compare selected policies or practices by testing alternative hypotheses about the system being managed. From Glossary of Forestry Terms: adaptive management rigorously combines management, research, monitoring, and means of changing practices so that credible information is gained and management activities are modified by experience

Avulsion: the abrupt natural diversion of stream flow from an established channel into a new channel. The abandoned channel may be left dry with flow passing through it only during high flow periods. The new channel may be a re-occupied channel or may be a newly eroded channel. Avulsion may occur as a result of log jams or landslide debris re-directing flow away from the established channel.

Bankfull width: the width of flow within a stream channel that is just contained within the channel banks. Commonly bankfull width is taken to be the distance perpendicular to stream flow between the limits of terrestrial vegetation on both sides of the stream.

Best Management Practices (BMPs): a practice or combination of practices that are determined to be the most technologically or economically feasible means of preventing or managing potential impacts.

Bio-Standards: are estimates of abundance or output that are used to predict responses, in terms of increases in fish numbers or biomass, due to specific watershed restoration activities. Typically measured in terms of number or biomass of a species per unit area or kilometer of stream.

Biotechnical slope stabilization: defined by Gray (1991) as the combined use of mechanical elements (or structures) and biologic elements (or plants) to arrest and prevent slope failures and erosion. Both biological and mechanical elements must function together in an integrated and complementary manner. Biotechnical stabilization can be characterized by the conjunctive use of live vegetation with retaining structures and revetments. It is also characterized by the combined use of vegetation with structural-mechanical elements in ground cover systems. (McCullah, 1999).

Bonded Fibre Matrix Material (BFM): "a bonded fiber (sic) matrix is a continuous layer of elongated fiber (sic) strands held together by a water-resistant bonding agent. It eliminates direct rain drop impact on soil (it has no holes larger than 1 mm in size) it allows no gaps between the product and the soil and it has a high water-holding capacity." (from http://www.revex.com/rvx_bfl.htm). Bonded fibre matrices will not address soil instability problems or sheet, rill, gully or other erosional processes except raindrop erosion (Polster, 1999 - Soil Bioengineering course manual).

Component Level Objective: restoration objectives for watershed components, including hillslopes, riparian areas, stream channels and fish habitat. Sub-components could include roads, landslides and gullies for hillslopes; streambank and floodplain for riparian; and off-channel and in-channel for streams.

Coppice: "small wood of underwood and small trees, grown for periodical cutting;" (The Concise Oxford Dictionary of Current English. 4th Edition, 1951). Coppice is also used as a verb meaning "to form a coppice by cutting small trees and brush and allowing it to resprout with many stems".

Debris Flow: involve the rapid downstream movement of liquefied sediment and woody debris. When confined in linear slope depressions or gullies they referred to as channelized debris flows or debris torrents. Debris flows usually start as relatively small events, but quickly swell in volume as they move downstream and entrain sediment, woody debris, slide debris, sidewall material, and road prism material into the flow matrix. Debris flows can travel for long distances and can be very destructive.

Debris Flood: involve the [illegible] of large volumes of sediment and woody debris down gully systems by large volumes of water. Usually the flowing mass associated with debris floods is less dense and moves slower than for channelized debris flows, but is more dense and moves faster than normal water transport.

Edatopic: an edatopic grid is a two-dimensional display of site series according to soil moisture and nutrient regime classes." (Green and Klinka, 1994)

Effectiveness Evaluations: assessments that answers the question of whether or not restoration has been effective in attaining or initiating the process to achieve the desired future condition and in meeting restoration objectives. Effectiveness evaluations are more complex than compliance inspections and requires an understanding of the physical, biological and sometimes the social factors that influence ecosystems. The word monitoring may also be used by other agencies, for example the U.S. Forest Service, to refer to evaluations

Erosion Control Revegetation Mat (ECRM): are blankets composed of a variety of materials designed to protect the surface of the soil from erosion. When coupled with seeding prior to blanket installation, the erosion control mat is said to protect the seed from erosion. Erosion control mats may be made of coir (coconut fibres) straw with polypropylene (fishing line type material), paper strips woven in polypropylene, etc.

Evaluation Objective: an objective that identifies the reason(s) for conducting effectiveness evaluations.

Gully System: is a steep headwater channel on a hillslope and comprised of a headwall, a transport zone and in some cases a fan. It acts as a conduit for water, sediment and woody debris.

Headscarp: A steep surface on the undisturbed ground at the head of a landslide, caused by movement of slide material away from the undisturbed ground.

Hydrophytic: moisture loving, as a hydrophytic plant is one that thrives on moist sites.

Inspections: are conducted during the course of watershed restoration activities to ensure that the work is completed as prescribed or to the standards defined in the contract. The main purpose is to ensure that errors and omissions are corrected prior to payment. Inspections are typically required for all projects with field inspections, and are generally carried out both during and at the completion of restoration works. Inspections may also be referred to as implementation monitoring or compliance monitoring.

Intensive Effectiveness Evaluations: a relatively detailed intensive effectiveness evaluation involving specialized study design with comprehensive data collection and analysis; generally quantitative measurements, but can include qualitative information. In comparison to routine evaluations, intensive evaluations are more focused and provide statistically defensible results. Focus can range from evaluation of specific treatments for single restoration objectives to integrated restoration treatments for multiple restoration objectives throughout entire watersheds.

Mesic: "conditioned by temperate moist climate, neither xeric (dry) nor hydric (wet)." (from A Dictionary of Scientific Terms. D. Van Nostrand Company, Inc. Princeton, New Jersey. 595 pp.)

Oligotropic: "providing or pertaining to inadequate nutrition; opposite of eutrophic." (from A Dictionary of Scientific Terms as above). Many coastal streams are considered oligotrophic as they are low in nutrients. Similarly ravelling gravel slopes or rock outcrops would typically be considered oligotrophic while cedar-alder-skunk cabbage-nettle-devil's club sites would be considered eutrophic or rich sites.

Operational Techniques Refinement: a special category of effectiveness evaluations that requires control and manipulation of restoration treatments in order to answer the questions: did a new treatment work, how well did it work relative to other treatments, and at what cost did it work.

Permanent Deactivation: deactivation carried out when the road will no longer be used by the person required to deactivate it under section 64 of the Forest Practices Code of B.C. Act. Permanent deactivation includes measures to stabilize the road prism and clearing width and to restore and maintain natural surface and subsurface drainage patterns. Stream and cross-drain culverts are removed, bridge superstructures and in some cases bridge substructures are removed, and where practicable measures to increase site productivity are carried out.

Qualified Registered Professional: means, with respect to an activity for which this regulation requires a qualified registered professional, a person who:

a) has appropriate education and experience to carry out the activity, and

b) is a member of, or licensed by, a regulatory body in British Columbia that has the legislated authority to regulate its members or licensees performing the activity.

Qualitative Data: the assignment of a value, such as good or bad, to a variable that would normally lack a means of quantification by standard measurement methods (length, width, volume)

Quantitative Data: the measurement of a value or quantity using standard measurement methods (length, width, volume)

Response Indicators: a variable that acts as an indirect indicator of treatment effectiveness.

Response Variable: a variable measured to assess the outcome of an experiment.

Routine Evaluations: a relatively low intensity evaluation, based on answering the question 'Is the treatment present, structurally stable, in need of remedial work and functioning as intended?' It doesn't require a specialized study design and may include qualitative and/or quantitative measurements.

Semi-Permanent Deactivation: deactivation carried out if

i) regular use of the road is to be suspended for more than one year but less than 3 years, and

either the road is in a remote location accessible only by air or water or in an area that has a moderate or high likelihood of landslides as determined by a terrain stability field assessment, or

ii) regular use of the road is to be suspended for more than 3 years.

Sidescarp: A steep surface on the undisturbed ground at the side of a landslide, caused by movement of slide material away from the undisturbed ground.

Soil bioengineering: defined by Sotir (1995) as involving the use of plants exclusively for soil and slope stabilization. The plant parts themselves, roots and stems, serve as the main structural and mechanical elements in a slope protection system. Live cuttings and rooted plants are imbedded in the ground in various arrays that the serve as soil reinforcements, hydraulic drains, and barriers to earth movement. (McCullah, 1999).

Variable: an evaluation parameter that changes measurably in character or number in response to environmental conditions, either through restoration treatments or natural events.

Watershed Level Objective: an objective that describes a desired future condition for the watershed typically achieved by attaining component level restoration objectives.

List of Acronyms

AMM	ACCESS MANAGEMENT MAP
ATV	All-Terrain Vehicle
BCFCSN	British Columbia Forestry Continuing Studies Network
CAP	Channel Assessment Procedure
FDP	Forest Development Plan
FERIC	Forest Engineering Research Institute of Canada
FPC	Forest Practices Code
FRBC	Forest Renewal British Columbia
GAP	Gully Assessment Procedure
GPS	Global Positioning System
IWRP	Integrated Watershed Restoration Plan
LRAP	Landslide Rehabilitation Assessment Procedure
LRMP	Land and Resource Management Plan
SOP	Standard Operating Procedure
TRIM	Terrain Resource Inventory Mapping
TSM	Terrain Stability Mapping
USDA	United States Department of Agriculture
WAP	Watershed Assessment Procedure
WRP	Watershed Restoration Program

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Best Management Practices Handbook:

Hillslope Restoration in British Columbia

Feedback Request

The authors would appreciate any feedback on information presented in this handbook including discussion of techniques, design and format of the document, subjects that may require further clarification and additional topics that should be considered for inclusion.

For any of the restoration techniques discussed, site specific conditions will be the main factors that influence their effectiveness. Experiences, either positive or negative, with any of the techniques discussed may prove valuable for inclusion in future or updated versions of this document. As well, any photographs depicting relevant activities or work will be considered for inclusion.

Comments and/or photographs can be sent to Brendan Holden at the Ministry of Forests in Victoria:

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Appendix I: Inventory Attributes

The following lists of attributes are intended to illustrate the types of information and data to be considered during planning and inventory projects. These lists should not be applied as a standard or considered exhaustive. The precise types of information to be included in an inventory will depend on the watershed and on the judgment of the individuals carrying out the assessment.

Typical Road Inventory Attributes

- a unique identifier for the road segment or road system
- length of road segment or road system
- estimated or known year the road was built
- inferred or known construction method used to build road (e.g. bulldozer, backhoe, winter construction)
- degree of revegetation occuring on the road
- location if different from base maps
- any observed instability indicators
- any anticipated erosion problems (hazards)
- known existing access and deactivation levels
- planned access and deactivation levels
- interpreted slope stability hazard rating
- interpreted consequence rating if a slope stability event occurs
- interpreted risk rating from hazard and consequence
- estimated priority rating (based on risk rating) for deactivation assessment (WRP Stage II Assessments and Prescriptions), if any
- suggested potential treatment of road, if any (e.g., water management or pullback)
- type of field assessment and qualifications of personnel required, if any
- estimated time and cost required for detailed field assessments, if any
- a preliminary access strategy (for reactivation and following deactivation)

Typical Landslide Inventory Attributes

- unique identifier for each landslide
- GPS location
- type of landslide (e.g. 7 class system of Rollerson and Fannin, 1992, or Cruden and Varnes , 1997 or LRAP)
- area of landslide in hectares (estimated from photos or measured in field)
- point of origin of landslide (e.g. road fill, road cut, cutblock or unlogged area)
- point of initiation of the landslide on the landscape (e.g. upper slope, lower slope)
- interpreted surficial geology at site of initiation
- estimated runout location (e.g. termination of slide on slope or in gully)

- interpreted degree of revegetation (may be repeated for historical photos to assess change in cover over time)
- estimated availability of local seeds and brush to landslide from surrounding vegetation
- interpreted risk of further landslide activity
- interpreted current active processes, if any (i.e. dry ravelling, surface erosion, stream rilling)
- estimated potential risks to downslope resources
- estimated priority for detailed assessment (WRP Stage II Assessments and Prescriptions), if any
- suggested potential remedial treatments, if any
- estimated time and cost required for detailed field assessments, if any

Typical Gully Inventory Attributes

- a unique gully identifier
- the number of years since harvesting occurred
- the number of road crossings over the gully
- the estimated or measured length of the gully
- the estimated bankfull width of the floor of the gully
- the estimated water transport and debris flow transport potential
- identified sediment sources feeding into the gully
- identified receiving location for sediment transported by the gully
- interpreted degree of revegetation of the gully
- estimated potential risks to downslope resources
- estimated priority for detailed assessment (WRP Stage II Assessments and Prescriptions), if any
- suggested potential remedial treatments, if any
- estimated time and cost for detailed field assessments, if any

Typical Riparian Area Attributes

- unique identifier for each riparian area
- dimensions of riparian area (e.g. length, width and overall area)
- extent of logging along channel margins
- age and type of second growth
- objective for potential treatment of site, if any
- suggested strategy for treating site, if any
- estimated benefit to watershed or component level objectives from treatment of site (e.g. fish habitat, water quality and stream health)
- estimated risk to riparian management treatments from potential upslope landslide events, if any
- estimated priority for detailed assessment (WRP Stage II Assessments and Prescriptions), if any
- estimated time and cost for detailed field assessments, if any

Typical Stream Channel Attributes

- unique identifier for each stream reach
- length of the stream reach
- stream channel class according to the Forest Practices Code (i.e. S1 to S4)
- stream channel classification based on the Channel Assessment Procedure (CAP) or comparable classification (e.g. Rosgen, 1994)
- sediment sources actively feeding the stream reach
- objective for potential treatment of site, if any
- suggested in-stream rehabilitation strategy for treating site, if any
- estimated benefit to watershed or component level objectives from treatment of site (e.g. fish habitat, water quality and stream health), if any
- estimated risk to in-stream treatments from potential upslope landslide events, if any
- estimated priority for detailed assessment (WRP Stage II Assessments and Prescriptions), if any
- estimated time and cost required for detailed field assessments, if any

Appendix II: Example – Risk Assessment Matrices

The following example risk assessment matrices are only illustrative and should not be considered a procedural standard. Examples 1A and 1B were derived for use on coastal watersheds for use in office-based overview assessments and for identifying project priorities. Interior watersheds may involve criteria related to erosion of fine grained soils. Example 2 was developed to include a rating of restoration feasibility along with risk and consequence in the determination of project priority. Practitioners should develop specific criteria for each project area, sub-basin or road system in consultation with stakeholders.

Rating	***Example 1A**: Road Hazard and Consequence Classification Criteria for use in Office-based Overview Assessments*
	Criteria
High (H)	**Hazard**
Moderate (M)	♦ Evidence of mass wasting along design segment; ♦ Approximately 50 % or more of similar design segments show mass wasting; and, ♦ Steeply gullied terrain, slopes in excess of 60 % unless on bedrock.
Low (L)	♦ Minor evidence of mass wasting along design segment; ♦ Approximately 25% or more of similar design segments show mass wasting; ♦ Steep terrain on bedrock with slopes in excess of 40 %; and, ♦ Moderately steeply gullied terrain, slopes in excess of 40 % unless on bedrock.
	♦ no evidence of mass wasting; ♦ slope generally less than 40 %; and, ♦ bedrock.
High (H)	**Consequence**
Moderate (M)	♦ Sediment delivery from source area leads directly into fish stream; and, ♦ life/safety-generally not addressed except for mainlines which have public traffic.
Low (L)	♦ Sediment delivery from source area leads directly into non-fish stream; and, ♦ Sediment delivery from source area leads indirectly to fish stream.
	♦ Sediment delivery from source area leads onto slopes; and, ♦ Sediment delivery from source area has no connection to streams.

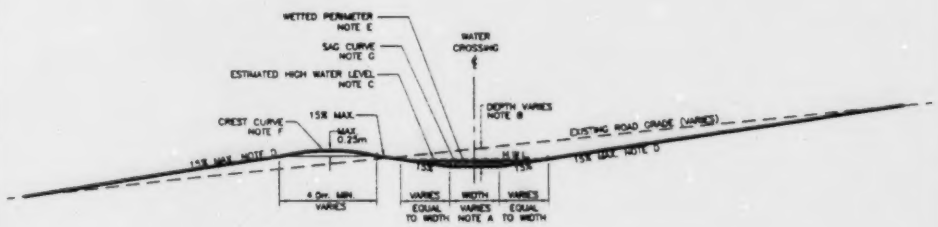
***Example 1B**: Risk Assessment Matrix*

Hazard/Consequence	Low	Moderate	High
Low	Very Low	Low	Moderate
Moderate	Low	Moderate	High
High	Moderate	High	Very High

Appendix III: Road Deactivation Typical Drawings

NOTE

THESE ARE TYPICAL DRAWINGS ONLY AND MAY NOT BE APPLICABLE OR APPROPRIATE IN EVERY SITUATION. DRAWING MODIFICATIONS, SPECIAL SITE PRESCRIPTIONS AND/OR PROFESSIONAL INPUT MAY BE REQUIRED TO ADDRESS ACTUAL SITE CONDITIONS.



TYPICAL ROAD PROFILE TEMPLATE #1

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL WATER CROSSING TEMPLATE NOTES

A) WATER CROSSING WIDTH = THE GREATER OF 2 TIMES THE DESIGN CULVERT ℄ OR THE WIDTH OF THE ACTIVE STREAM CHANNEL. WIDTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

B) WATER CROSSING DEPTH = DEPTH OF CUT FROM EXISTING ROAD GRADE TO WATER CROSSING INVERT AT INTERSECTION OF ROAD AND WATER CROSSING CENTRELINES. DEPTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

C) ESTIMATED HIGH WATER LEVEL = WATER CROSSING WIDTH X 0.15. (FOR ALL TEMPLATES EXCEPT #4)

D) MAXIMUM TEMPLATE GRADE MAY VARY AS DIRECTED BY LICENCEE /MINISTRY REPRESENTATIVE TO CONFORM TO ACTUAL SITE CONDITIONS.

E) WETTED PERIMETER TO BE CONSTRUCTED BELOW EXISTING ROAD GRADE.

F) CREST CURVES THAT FORM A TRANSITION BETWEEN THE SHAPE OF THE WATER CROSSING AND THE EXISTING ROAD ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. THE MAXIMUM CREST CURVE HEIGHT OF 0.25m IN 4.0m HORIZONAL DISTANCE AS SHOWN ON TEMPLETE WILL ACCOMMADATE ALL ACCESS LEVELS. (SEE TABLE A)

G) SAG CURVES THAT FORM THE BOTTOM OF THE WATER CROSSING ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. (SEE TABLE A)

SCALE 1:200

DRAWN N.K.
CHECKED M.L. APPROVED W.D. CRIPPS DATE JULY 14 1997

REV No.	REVISIONS	APPROVED	DATE
F			
E			
D			
C			
B			
A			

Province of British Columbia
MINISTRY OF FORESTS
KAMLOOPS FOREST REGION

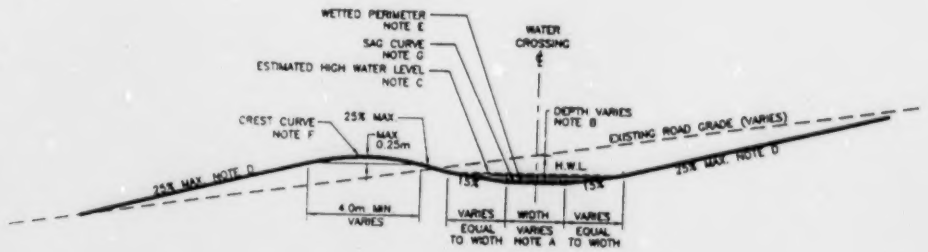
TYPICAL ROAD PROFILE TEMPLATE FOR FORDS
TWO-WHEEL DRIVE ACCESS
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE: JULY 14 1997
DRAWING No.: 012094-00-03-1
REVISION:

PREPARED BY: SAC-LANAUM FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 662-3555 FAX 662-7688

NOTE

THESE ARE TYPICAL DRAWINGS ONLY AND MAY NOT BE APPLICABLE OR APPROPRIATE IN EVERY SITUATION. DRAWING MODIFICATIONS, SPECIAL SITE PRESCRIPTIONS AND/OR PROFESSIONAL INPUT MAY BE REQUIRED TO ADDRESS ACTUAL SITE CONDITIONS.



TYPICAL ROAD PROFILE TEMPLATE #2

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL WATER CROSSING TEMPLATE NOTES

A) WATER CROSSING WIDTH = THE GREATER OF 2 TIMES THE DESIGN CULVERT ⌀ OR THE WIDTH OF THE ACTIVE STREAM CHANNEL. WIDTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

B) WATER CROSSING DEPTH = DEPTH OF CUT FROM EXISTING ROAD GRADE TO WATER CROSSING INVERT AT INTERSECTION OF ROAD AND WATER CROSSING CENTRELINES. DEPTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

C) ESTIMATED HIGH WATER LEVEL = WATER CROSSING WIDTH X 0.15 (FOR ALL TEMPLATES EXCEPT ⌀4)

D) MAXIMUM TEMPLATE GRADE MAY VARY AS DIRECTED BY LICENCEE /MINISTRY REPRESENTATIVE TO CONFORM TO ACTUAL SITE CONDITIONS.

E) WETTED PERIMETER TO BE CONSTRUCTED BELOW EXISTING ROAD GRADE.

F) CREST CURVES THAT FORM A TRANSITION BETWEEN THE SHAPE OF THE WATER CROSSING AND THE EXISTING ROAD ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. THE MAXIMUM CREST CURVE HEIGHT OF 0.25m IN 4.0m HORIZONAL DISTANCE AS SHOWN ON TEMPLETE WILL ACCOMMADATE ALL ACCESS LEVELS. (SEE TABLE A)

G) SAG CURVES THAT FORM THE BOTTOM OF THE WATER CROSSING ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. (SEE TABLE A)

SCALE 1:200

PREPARED BY: SMC-LAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 682-3555 FAX 682-7668

DRAWN N.K. CHECKED M.L. APPROVED W.D. CRIPPS DATE JULY 14 1997

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Province of British Columbia
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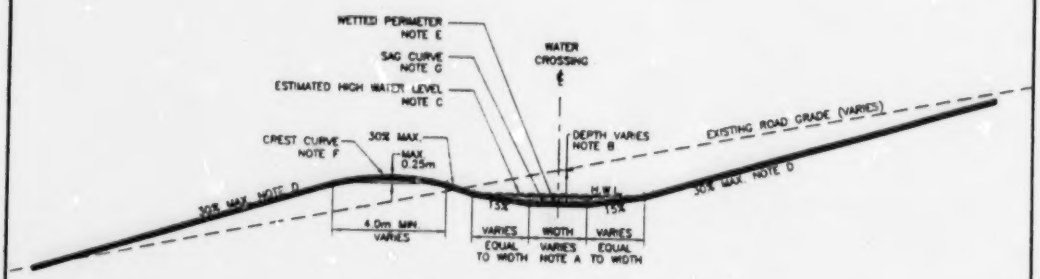
TYPICAL ROAD PROFILE TEMPLATE FOR FORDS
FOUR-WHEEL DRIVE ACCESS
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE	DRAWING No.	REVISION
JULY 14 1997	012094-00-03-2	

NOTE

THESE ARE TYPICAL DRAWINGS ONLY AND MAY NOT BE APPLICABLE OR APPROPRIATE IN EVERY SITUATION. DRAWING MODIFICATIONS, SPECIAL SITE PRESCRIPTIONS AND/OR PROFESSIONAL INPUT MAY BE REQUIRED TO ADDRESS ACTUAL SITE CONDITIONS.



TYPICAL ROAD PROFILE TEMPLATE #3

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL WATER CROSSING TEMPLATE NOTES

A) WATER CROSSING WIDTH = THE GREATER OF 2 TIMES THE DESIGN CULVERT ø OR THE WIDTH OF THE ACTIVE STREAM CHANNEL. WIDTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

B) WATER CROSSING DEPTH = DEPTH OF CUT FROM EXISTING ROAD GRADE TO WATER CROSSING INVERT AT INTERSECTION OF ROAD AND WATER CROSSING CENTRELINES. DEPTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

C) ESTIMATED HIGH WATER LEVEL = WATER CROSSING WIDTH X 0.15. (FOR ALL TEMPLATES EXCEPT #4)

D) MAXIMUM TEMPLATE GRADE MAY VARY AS DIRECTED BY LICENCEE /MINISTRY REPRESENTATIVE TO CONFORM TO ACTUAL SITE CONDITIONS.

E) WETTED PERIMETER TO BE CONSTRUCTED BELOW EXISTING ROAD GRADE.

F) CREST CURVES THAT FORM A TRANSITION BETWEEN THE SHAPE OF THE WATER CROSSING AND THE EXISTING ROAD ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. THE MAXIMUM CREST CURVE HEIGHT OF 0.25m IN 4.0m HORIZONAL DISTANCE AS SHOWN ON TEMPLETE WILL ACCOMMADATE ALL ACCESS LEVELS. (SEE TABLE A)

G) SAG CURVES THAT FORM THE BOTTOM OF THE WATER CROSSING ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. (SEE TABLE A)

SCALE 1:200

PREPARED BY: SAC-LAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 682-3555 FAX 682-7668

DRAWN N.K.
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TYPICAL ROAD PROFILE TEMPLATE FOR FORDS
ALL-TERRAIN VEHICLE OR WALKING ACCESS
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE	DRAWING No.	REVISION
JULY 14 1997	012094-00-03-3	

NOTE
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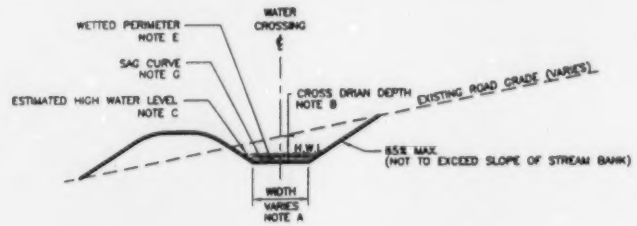

TYPICAL ROAD PROFILE TEMPLATE #4
(REESTABLISH STREAM CROSSING)

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL WATER CROSSING TEMPLATE NOTES

A) WATER CROSSING WIDTH = THE GREATER OF 2 TIMES THE DESIGN CULVERT ø OR THE WIDTH OF THE ACTIVE STREAM CHANNEL. WIDTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

B) WATER CROSSING DEPTH = DEPTH OF CUT FROM EXISTING ROAD GRADE TO WATER CROSSING INVERT AT INTERSECTION OF ROAD AND WATER CROSSING CENTRELINES. DEPTH IS SPECIFIED ON ROAD DEACTIVATION PRESCRIPTION PLANS.

C) ESTIMATED HIGH WATER LEVEL = WATER CROSSING WIDTH X 0.15. (FOR ALL TEMPLATES EXCEPT #4)

D) MAXIMUM TEMPLATE GRADE MAY VARY AS DIRECTED BY LICENCEE /MINISTRY REPRESENTATIVE TO CONFORM TO ACTUAL SITE CONDITIONS.

E) WETTED PERIMETER TO BE CONSTRUCTED BELOW EXISTING ROAD GRADE.

F) CREST CURVES THAT FORM A TRANSITION BETWEEN THE SHAPE OF THE WATER CROSSING AND THE EXISTING ROAD ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. THE MAXIMUM CREST CURVE HEIGHT OF 0.25m IN 4.0m HORIZONAL DISTANCE AS SHOWN ON TEMPLETE WILL ACCOMMODATE ALL ACCESS LEVELS. (SEE TABLE A)

G) SAG CURVES THAT FORM THE BOTTOM OF THE WATER CROSSING ARE TO BE CONSTRUCTED TO ACCOMMODATE THE SPECIFIED ACCESS LEVEL. (SEE TABLE A)

SCALE 1:200

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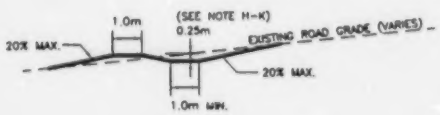
TYPICAL ROAD PROFILE TEMPLATE
FOR FORDS
NO ACCESS (CLOSED)
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE: JULY 14 1997
DRAWING No.: 012094-00-03-4
REVISION:

PREPARED BY: SAC-LAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION. 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 682-3555 FAX 682-7668

NOTE
THESE ARE TYPICAL DRAWINGS ONLY AND MAY NOT BE APPLICABLE OR APPROPRIATE IN EVERY SITUATION. DRAWING MODIFICATIONS, SPECIAL SITE PRESCRIPTIONS AND/OR PROFESSIONAL INPUT MAY BE REQUIRED TO ADDRESS ACTUAL SITE CONDITIONS.



TYPICAL CROSS DITCH TEMPLATE #1

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL CROSS DITCH TEMPLATE NOTES

H) CROSS DITCH TEMPLATES ARE DESIGNED TO CARRY A DISCHARGE EQUIVALENT TO A 600mm ø CULVERT

I) CROSS DITCHES ARE TO BE CONSTRUCTED AT LOCATIONS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS

J) CROSS DITCH TEMPLATES USED MUST BE CONSISTENT WITH ACCESS LEVELS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS

K) CROSS DITCH TEMPLATES MUST BE RESHAPED AT THE INLET END TO ALLOW A DIRECT HYDRAULIC CONNECTION TO THE ROAD SIDE DITCH WITHOUT RESTRICTING THE SPECIFIED ACCESS LEVEL

SCALE 1:200

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TYPICAL CROSS DITCH TEMPLATE
TWO-WHEEL DRIVE ACCESS
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE	DRAWING No.	REVISION
JULY 14 1997	012094-00-03-5	

PREPARED BY: SAC-LAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 682-3555 FAX 682-7688

NOTE

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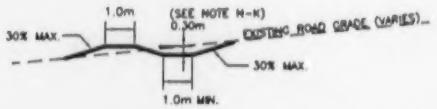

TYPICAL CROSS DITCH TEMPLATE #2

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL CROSS DITCH TEMPLATE NOTES

H) CROSS DITCH TEMPLATES ARE DESIGNED TO CARRY A DISCHARGE EQUIVALENT TO A 600mmø CULVERT

I) CROSS DITCHES ARE TO BE CONSTRUCTED AT LOCATIONS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS

J) CROSS DITCH TEMPLATES USED MUST BE CONSISTENT WITH ACCESS LEVELS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS

K) CROSS DITCH TEMPLATES MUST BE RESHAPED AT THE INLET END TO ALLOW A DIRECT HYDRAULIC CONNECTION TO THE ROAD SIDE DITCH WITHOUT RESTRICTING THE SPECIFIED ACCESS LEVEL

SCALE 1:200

PREPARED BY: SMC-LAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 662-3555 FAX 662-7688

DRAWN M.K.
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TYPICAL CROSS DITCH TEMPLATE
FOUR-WHEEL DRIVE ACCESS
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE	DRAWING No.	REVISION
JULY 14 1997	012094-00-03-6	

NOTE

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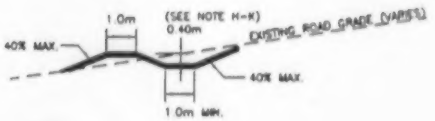

TYPICAL CROSS DITCH TEMPLATE #3

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS'. DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL CROSS DITCH TEMPLATE NOTES

H) CROSS DITCH TEMPLATES ARE DESIGNED TO CARRY A DISCHARGE EQUIVALENT TO A 600mm∅ CULVERT

I) CROSS DITCHES ARE TO BE CONSTRUCTED AT LOCATIONS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS

J) CROSS DITCH TEMPLATES USED MUST BE CONSISTENT WITH ACCESS LEVELS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS

K) CROSS DITCH TEMPLATES MUST BE RESHAPED AT THE INLET END TO ALLOW A DIRECT HYDRAULIC CONNECTION TO THE ROAD SIDE DITCH WITHOUT RESTRICTING THE SPECIFIED ACCESS LEVEL.

SCALE 1:200

PREPARED BY: SHC-LIAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 682-3555 FAX 682-7688

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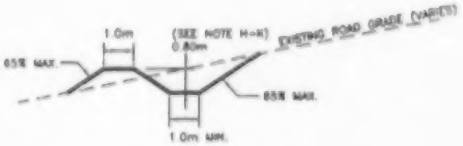
KAMLOOPS FOREST REGION

TYPICAL CROSS DITCH TEMPLATE
ALL-TERRAIN VEHICLE OR WALKING ACCESS
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE: JULY 14 1997
DRAWING No.: 012094-00-03-7
REVISION:

NOTE
THESE ARE TYPICAL DRAWINGS ONLY AND MAY NOT BE APPLICABLE OR APPROPRIATE IN EVERY SITUATION. DRAWING MODIFICATIONS, SPECIAL SITE PRESCRIPTIONS AND/OR PROFESSIONAL INPUT MAY BE REQUIRED TO ADDRESS ACTUAL SITE CONDITIONS.



TYPICAL CROSS DITCH TEMPLATE #4

GENERAL NOTES:

1. TYPICAL WATER CROSSING TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO FACILITATE VEHICULAR ACCESS AT WATER CROSSINGS OR OTHER LOCATIONS.
2. TYPICAL CROSS DITCH TEMPLATES ARE USED TO DESCRIBE THE SIZE AND SHAPE OF A DIP TO BE CONSTRUCTED IN A ROAD TO CARRY ROAD SURFACE WATER AND DITCH WATER OFF OR ACROSS THE ROAD AND TO PROVIDE VEHICULAR ACCESS ALONG THE ROAD.
3. FOR CROSS DITCH AND FORD DEFINITIONS AND NOTES SEE DWG. 05
4. FOR ARMOURING DETAILS OF FORDS SEE DWG. 04 'TYPICAL FORD/SQUAMISH CULVERT DETAILS'.
5. THIS DRAWING TO BE READ IN CONJUNCTION WITH DWG. 04 'TYPICAL FORD AND SQUAMISH CULVERT DETAILS', DWG. 05 'TYPICAL WATER CONTROL METHODS'.

TYPICAL CROSS DITCH TEMPLATE NOTES

H) CROSS DITCH TEMPLATES ARE DESIGNED TO CARRY A DISCHARGE EQUIVALENT TO A 600mmø CULVERT.

I) CROSS DITCHES ARE TO BE CONSTRUCTED AT LOCATIONS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS.

J) CROSS DITCH TEMPLATES USED MUST BE CONSISTENT WITH ACCESS LEVELS AS SPECIFIED ON THE ROAD DEACTIVATION PRESCRIPTIONS PLANS.

K) CROSS DITCH TEMPLATES MUST BE RESHAPED AT THE INLET END TO ALLOW A DIRECT HYDRAULIC CONNECTION TO THE ROAD SIDE DITCH WITHOUT RESTRICTING THE SPECIFIED ACCESS LEVEL.

SCALE 1:200

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Province of British Columbia
MINISTRY OF FORESTS
KAMLOOPS FOREST REGION

TYPICAL CROSS DITCH TEMPLATE
NO ACCESS (CLOSED)
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE	DRAWING No.	REVISION
JULY 14 1997	012094-00-03-8	

PREPARED BY: SAC-UNAJA FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 662-3555 FAX 662-7688

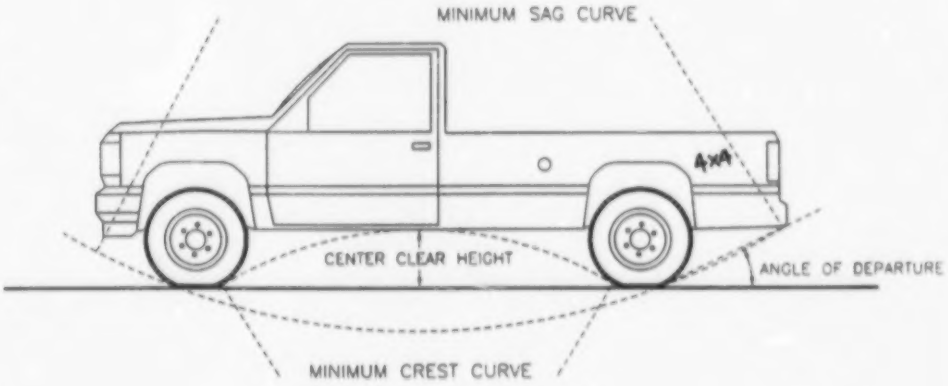
TABLE A

(FOR INFORMATION ONLY)

VEHICLE DIMENSION SUMMARY TABLE

VEHICLE CLASSIFICATION	SUB-CLASSIFICATION	CENTER CLEAR HEIGHT mm	ANGLE OF DEPARTURE %	MINIMUM SAG CURVE mm	MINIMUM CREST CURVE mm	MAX HT OF CREST CURVE IN 4.0m HORZ DISTANCE mm	MINIMUM WATER CROSSING WIDTH mm
TWO WHEEL DRIVE TRUCKS	COMPACT PICK-UP	270	50%	4400	3000	750	700
	FULL SIZE PICK-UP	270	45%	5400	3800	570	900
	EXTENDED CAB PICK-UP	300	43%	6300	4850	430	1000
	CREW CAB PICK-UP	300	39%	7100	7000	280	1000
	MAX.	**300**	**50%**	**7100**	**7000**	**750**	**1000**
	MIN.	**270**	**39%**	**4400**	**3000**	**280**	**700**
FOUR WHEEL DRIVE TRUCKS	COMPACT PICK-UP	370	61%	4200	3100	730	600
	FULL SIZE PICK-UP	300	45%	5800	4200	510	900
	EXTENDED CAB PICK-UP	350	50%	5400	4040	530	800
	CREW CAB PICK-UP	340	46%	6900	6200	330	1000
	COMPACT SPORT UTILITY	300	55%	4000	2650	910	600
	FULL SIZE SPORT UTILITY	310	38%	6100	3300	670	900
	MAX.	**370**	**61%**	**6900**	**6200**	**910**	**1000**
	MIN.	**300**	**38%**	**4000**	**2650**	**330**	**600**
SPECIAL ACCESS VEHICLE	FIRE PROTECTION VEHICLE	430	32%	9300	3350	660	1300

MINIMUM VEHICLE GROUND CLEARANCES AND ROAD PROFILE TEMPLATE DIMENSIONS BY VEHICLE SUB-CLASSIFICATION



NOT TO SCALE

DRAWN: H.K.
CHECKED: M.L. APPROVED: W.D. CRIPPS DATE: JULY 14 1997

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VEHICLE DIMENSION SUMMARY TABLE
TABLE A
TYPICAL ROAD DEACTIVATION PRESCRIPTIONS DRAWING

DATE: JULY 14 1997 | DRAWING No.: 012094-00-03-9 | REVISION:

PREPARED BY: SAC-LAVALIN FOR THE MINISTRY OF FORESTS, KAMLOOPS FOREST REGION 1800-1075 WEST GEORGIA STREET VANCOUVER B.C. V6E 3C9 PH 682-3555 FAX 682-7668